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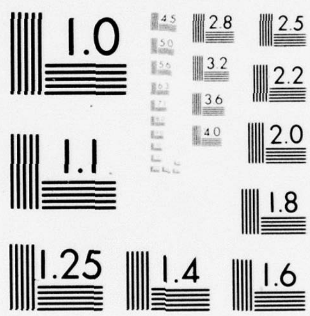

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TECHNICAL REPORT H-77-5

MARYSVILLE LAKE HYDROTHERMAL STUDY

Report I

900-MW PROJECT

Hydraulic and Mathematical Model Investigation

by

Darrell G. Fontane, Mark S. Dortch, Charles H. Tate, Jr., Bruce Loftis

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Report I of a Series

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Hydraulic models; Marysville Lake; Mathematical models; Pumped-storage; Water temperature		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This study was conducted to determine if the proposed Marysville Lake pumped-storage hydropower (900-MW) project could satisfy downstream water temperature objectives. A one-dimensional numerical model was used for simulation and prediction of temperatures within and downstream of Marysville Lake. A physical hydraulic model was used for study and description of the hydrodynamic response of the project to pumped-storage hydropower operations. The physical model, (Continued)		

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20. ABSTRACT (Continued).

constructed to a distorted scale of 1:1600 horizontally and 1:160 vertically, simulated the dynamic, unsteady-state, density-stratified flows through Marysville Lake and the afterbay or reregulating pool. Information from the physical model was used to modify existing algorithms and to develop new ones for the mathematical model. The mathematical model allowed simulation of the heat exchange characteristics so the thermal regimes within and downstream of the lake could be determined for various hydrologic and meteorologic conditions and various pumped-storage hydropower operations. Results of the study indicate that the project should satisfy the temperature objectives desired downstream.

PREFACE

The study reported herein was authorized by the Office, Chief of Engineers (OCE), U. S. Army, on 16 July 1975, at the request of the U. S. Army Engineer District, Sacramento (SPK).

This study pertains to the 900-MW power project and is Report 1 of a series. At the time this report was prepared, another study was being made of the same project with a greater power-producing capability (2250 MW). The report of that study will be published separately as Report 2.

The investigation was conducted during the period August 1975 to October 1976 in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division and Reservoir Water Quality Branch (Physical). The study was conducted by Messrs. M. S. Dortch, D. G. Fontane, B. Loftis, and C. H. Tate, Jr., with assistance from Mr. J. H. Riley. This report was prepared by Messrs. Fontane, Dortch, Tate, and Loftis and reviewed by Mr. Grace.

Representatives of WES and SPK met at SPK during November 1975 to discuss the scope, objectives, and approach of the study. During July 1976, representatives of WES, SPK, and the South Pacific Division (SPD) met to redefine the scope and objectives of the study. Mr. Dennis Huff of SPK was detailed to WES during September 1976 to become familiar with the mathematical model and to assist with the numerical simulations.

Directors of WES during this study were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609	kilometres
square feet	0.092903	square metres
square miles (U. S. statute)	2.58999	square kilometres
acres	4.046	square kilometres
acre-feet	1233.482	cubic metres
cubic feet per second	0.02832	cubic metres per second
British thermal unit	1055.056	joules
degrees Fahrenheit	5/9	degrees Celsius or Kelvins*

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

MARYSVILLE LAKE HYDROTHERMAL STUDY

900-MW PROJECT

Hydraulic and Mathematical Model Investigation

PART I: INTRODUCTION

Purpose and Scope of Study

1. This study was conducted to determine the ability of the Marysville Lake project to satisfy downstream water temperature objectives. The study required (a) understanding and description of the large-scale hydrodynamic phenomena within the project, (b) development of temperature profiles within Marysville Lake, and (c) determination of temperatures released from Marysville Lake, from the afterbay, and routed to the mouth of the Yuba River.

2. A physical hydrodynamic model and a numerical simulation model were used in the study. The physical model provided information relative to the hydrodynamic response of the prototype for various operational conditions. The numerical model provided the capability for assessing for year-long periods the effect of historical meteorologic and hydrologic data and various operating conditions on temperature regimes within and downstream of the project.

Project Description

3. The Marysville Lake project, authorized by Congress in the Flood Control Act of 7 November 1966 (Public Law 89-789) and modified by the Water Resources Development Act of 1976 (Public Law 94-587), will provide flood control for downstream areas, hydroelectric power, water for irrigation, recreation, and fishery enhancement. The project will be built and operated by the U. S. Army Corps of Engineers. Irrigation and power functions of the project will be integrated into the Central Valley Project of the U. S. Bureau of Reclamation.

4. The lake will be on the Yuba River about 17 miles* upstream from the city of Marysville (Figure 1) in north-central California. The project will consist of a multipurpose pool impounded by main dams on the Yuba River just above the Parks Bar Bridge and on the adjacent Dry Creek and an afterbay dam and pool for regulation of downstream flows. The afterbay will also be used to store water to be pumped back to the lake.

5. The project was relocated to the Parks Bar site from the authorized Browns Valley site following a review of alternatives in light of the recent energy crisis. Studies indicated that the Parks Bar site had greater potential for hydroelectric power, including pumped-storage. Also, the Parks Bar site was found to be more environmentally and socially acceptable.

6. The dam on the Yuba River will rise 368 ft above the streambed to el 570** and consist of a concrete, gravity-center section with earthfill abutments. The dam on Dry Creek will rise 328 ft above the streambed and consist entirely of earthfill. Both dams will be 7000 ft long. A channel will be excavated through the saddle between the Yuba River pool and the Dry Creek pool to facilitate the exchange of water between the pools during low lake levels. The lake will impound 916,000 acre-ft when the water is at the gross pool, el 560. At this elevation the pool will cover 6640 acres and will have 67 miles of shoreline. At minimum pool, el 428, the lake will have a storage capacity of 273,000 acre-ft and a surface area of 3180 acres. The afterbay will have a storage capacity of 40,400 acre-ft and a surface area of about 947 acres at gross pool, el 233.

7. A 900-megawatt (MW) peaking power plant with four 150-MW pump turbines and two 150-MW conventional turbines is planned for the Yuba River dam. Water would be released through the main power plant on an intermittent basis to produce power during peak demand hours. When power demand is low, the pump turbines would pump water from the

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

** All elevations (el) cited herein are in feet referred to mean sea level.

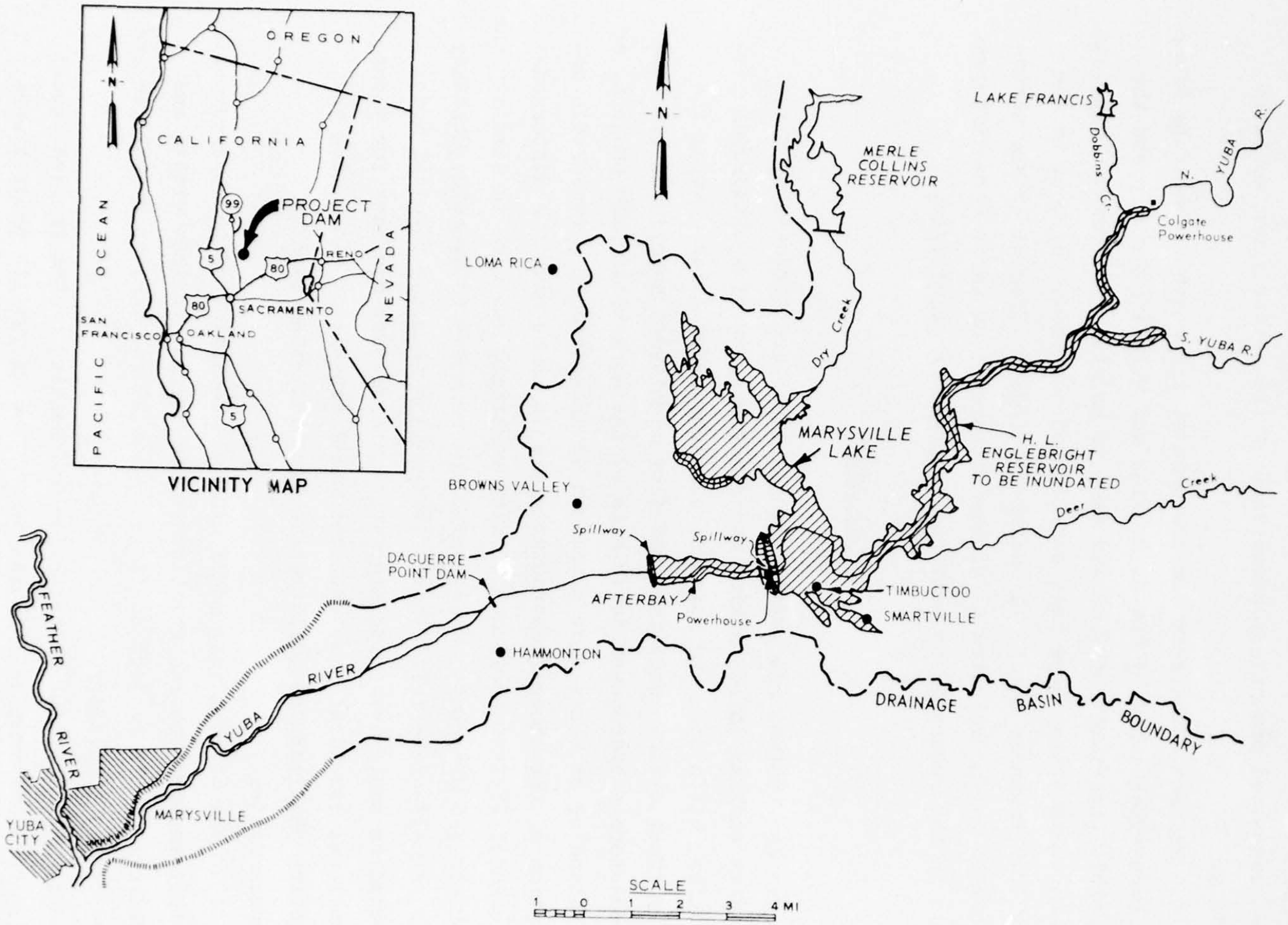


Figure 1. Location map

afterbay to the lake so the water can be reused. Studies indicate a 20-MW, base-load powerplant downstream of the afterbay dam would be feasible.

8. Maximum downstream temperatures at the mouth of the Yuba River have been established by the U. S. Fish and Wildlife Service and the California Department of Fish and Game to maintain anadromous fish runs. Minimum temperatures have been established for study purposes by the U. S. Army Engineer District, Sacramento (SPK). Special intake structures will be incorporated to enable withdrawal of water from different levels in the reservoir to meet the temperature objectives.

Approach

9. The thermal characteristics of lakes are affected by flow processes such as inflow mixing and placement, outflow withdrawal distribution, diffusion, and internal currents. For a lake having the highly dynamic flow conditions and flow magnitudes associated with the pumped-storage hydropower activities of the Marysville Lake project, an understanding of these flow processes is necessary if a reasonable description of the thermal characteristics is to be made. A distorted-scale model (1:1600 horizontal, 1:160 vertical) was used to simulate the reservoir and afterbay and determine the response to dynamic, unsteady-state, density-stratified flow. Information from the physical model was used to modify existing algorithms and develop new ones for a one-dimensional (vertical) mathematical model capable of simulating and budgeting physical and conservative chemical water quality characteristics.

10. The mathematical model allowed simulation of the hydrodynamic and heat exchange characteristics so the thermal regimes within and downstream of the project could be evaluated for various hydrologic and meteorologic conditions.

11. Prior to the construction and testing of the physical model, preliminary mathematical simulations of the Marysville project were performed and a preliminary report (Appendix A) was furnished to SPK.

The purpose of these preliminary simulations was to estimate the feasibility of the project to meet downstream temperature objectives and to indicate port locations that would enable these objectives to be satisfied. The results of the physical model and refined mathematical model were later used to more accurately determine the ability of the Marysville project to meet downstream temperature objectives.

PART II: PHYSICAL MODEL

Purpose

12. The purpose of the distorted-scale model was to aid in defining the hydrodynamics of Marysville Lake resulting from the planned operation of the prototype. The model was needed to determine the effects of unsteady generation and pumpback on the density stratification of Marysville Lake and afterbay and to help identify, validate, and quantify any modifications needed to the mathematical model for improving the reliability of the predictions.

Scale Relations

13. The predominant forces affecting density-stratified flows in lakes are inertia and gravity as modified by density differences. In such cases, hydraulic similarity between a model and prototype system requires that the ratio of inertial to gravitational forces, defined as the Froude number of flow, be the same in both the model and the prototype. With the density differences in the model set equal to those in the prototype, the accepted equations of hydraulic similitude, based on the Froudian relations, were used to express the mathematical relations between the dimensional and hydraulic quantities of the model and the prototype. Allowing for vertical scale distortion, the general relations for transfer of model data to prototype equivalents are as follows:

Dimension	Ratio	Scale Relation
Length in vertical direction	$L_r = L_y$	1:160
Length in horizontal direction	$L_r = L_x$	1:1600
Area in vertical plane	$A_r = L_x L_y$	1:256,000
Area in a horizontal plane	$A_r = L_x^2$	1:2,560,000

(Continued)

Dimension	Ratio	Scale Relation
Velocity	$V_r = L_y^{1/2}$	1:12.65
Time	$T_R = L_x/L_y^{1/2}$	1:126.5
Flow	$Q_r = L_x L_y^{3/2}$	1:3,238,172
Density difference	$\Delta\rho_r = 1$	1:1

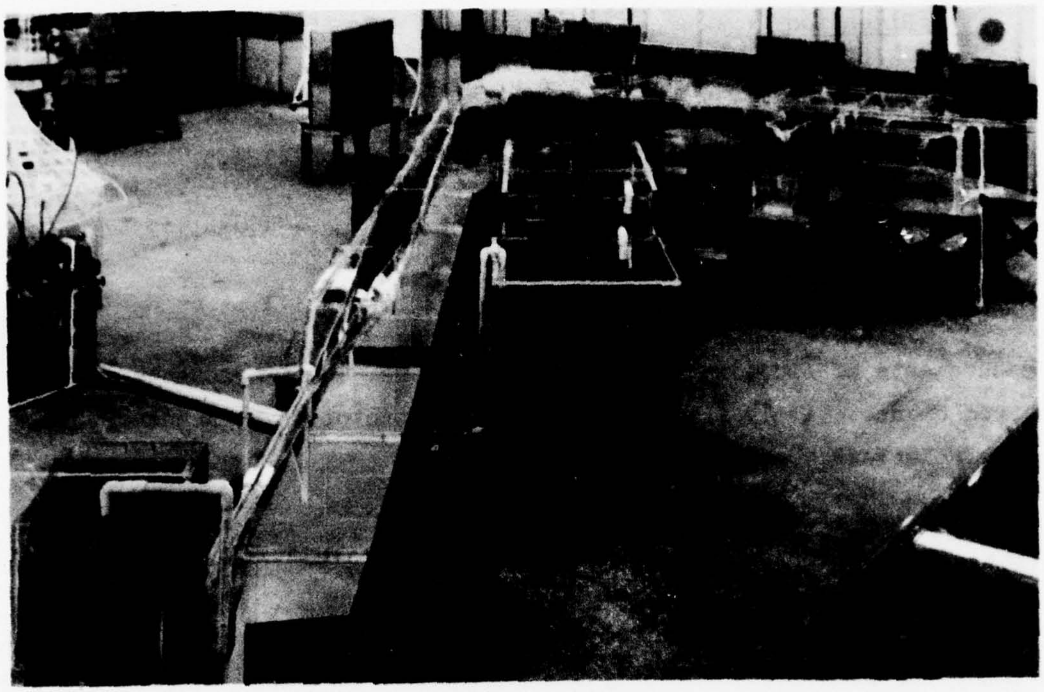
Measurements of flow, water-surface elevations, and time can be transferred quantitatively from the model to the prototype by means of the scale relations above.

Description

14. The model (Figure 2) was constructed to a distorted length scale ratio of 1:160 vertically and 1:1600 horizontally. Through vertical scale distortion, it was possible to preserve turbulent flow while simulating the entire reservoir and afterbay. It is necessary to maintain the same fundamental character of flow in the model as in the prototype. Use of an undistorted-scale model of the entire system would require a model of such large dimensions and discharge capacity to insure turbulent flow that the cost would be impractical. By horizontal scale compression, the total size of the model was reduced and hydraulic similitude was preserved.

15. The model lakes and afterbay were constructed of transparent plastic to facilitate photography and visual observations of currents vertically and longitudinally. The model approximated the geometry and reproduced the scaled elevation-storage relationships of the prototype lakes. The sides of the model flume were stepped vertically (Figure 3) to satisfy the above-mentioned requirements without visual distortion through the side. Urethane foam was contoured to simulate the topography upstream of the intake structures.

16. Saline and fresh waters were used to reproduce the density variations that are anticipated in the prototype due to temperature



a. View of upper reach of lake

b. View of lake in vicinity of dam

Figure 2. Marysville Lake hydrodynamic model

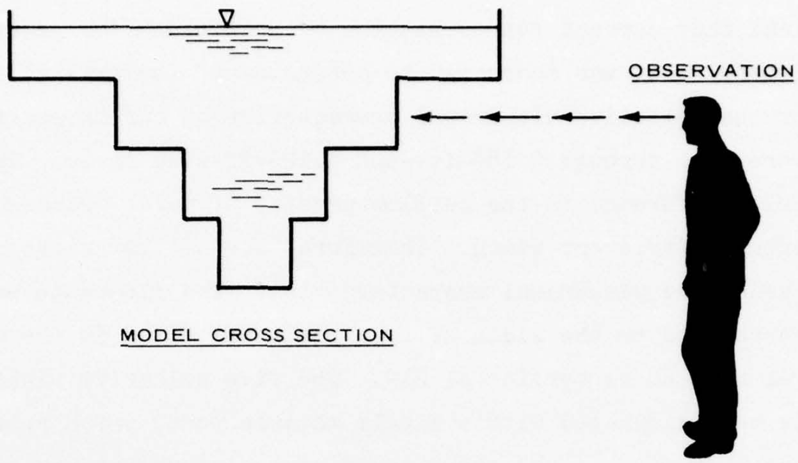


Figure 3. Example of model design for convenient observation

differences. Density measurements were obtained with conductivity and temperature sensors. The conductivity and density values were converted to density by means outlined in Reference 1. Velocity distributions were determined from video recordings of dye streak displacement. Various dyes were used to follow the water movement of particular interest.

17. The preliminary mathematical simulations indicated that five vertical locations of selective-withdrawal ports (℄ el 540, 500, 440, 375, and 350) and a floodgate located near the bottom (invert el 205) could be used to meet downstream temperature objectives. The prototype structure would consist of six intakes at each vertical level to accommodate the six turbines. Preliminary design established selective withdrawal-port dimensions of 50 ft wide by 10 ft high and floodgate dimensions of 28 ft wide by 28 ft high. Because of the difficulty of reproducing the small-scaled horizontal dimension of the outlet ports (0.031 ft per port), the horizontal ports at each level were combined into a single port in the model. The width of this port corresponded to the width of four ports which more accurately represented pumpback from the four pump turbines.

18. A width corresponding to six ports would have better represented flow during generation through the six turbines. However, the

correct representation of port width for pumpback was believed to be more critical than correct representation of port width for generation. A physical model test was conducted to determine if the smaller width would alter the selective withdrawal characteristics during generation. Releases were made through 0.188-ft- and 0.125-ft-wide ports. There was no measurable difference in the outflow density of water released from the two ports of different width. Therefore, the smaller width did not alter the selective withdrawal characteristics. The floodgate was also sized to correspond to the width of four ports and fixed in the model at invert el 205 and centerline el 219. The five selective withdrawal port levels were simulated with a single movable port, which represented four intakes at a given level, that could be positioned at any one of the five port elevations. This upper movable port emptied into a wet-well and was positioned by an electro-mechanical actuator.

19. Generation and pumpback hydrographs were simulated using a variable speed, reversible, programmable, positive displacement pump. Actuated butterfly valves were used to direct the flow through either the upper (selective withdrawal) port or the lower (floodgate) port. A constant head tank, rotameter, and gate valve were used to provide and regulate inflow from the Yuba River. Downstream releases from the afterbay were controlled by a rotameter and gate valve.

20. Model control devices could be operated manually or automatically from the control console (Figure 2b). Automatic control was achieved through analog signals generated by magnetic card readers that tracked input data. Automatic control allowed unsteady operation to proceed for extended simulation periods (4 weeks prototype time). Because the model was not able to reproduce surface heat exchange, realistic prototype simulations exceeding 4 weeks were not attempted because the meteorological effects could exceed the hydrodynamic effects.

Model Tests and Results

Prototype simulation

21. The anticipated thermal stratification conditions

(see Appendix A) for July of an average hydrologic and meteorologic year (1962) were simulated in the model. The model simulated a constant inflow from the Yuba River of 2288 cfs at a temperature of 14.7°C. The planned project operation scheme for the above-mentioned average year, which was furnished by the Sacramento District and was applied in the model, is presented below:

Turbine Configuration	Generation Flow	Pumpback Flow	Afterbay Release
2 conventional and 4 reversible turbines	37,700 cfs for 3.71 hr per day, 6 days per week; start at 5 pm	8200 cfs for 9 hr per night, 6 days per week; start at 10 pm	2360 cfs constant release

Generation and pumpback occur Monday through Saturday. With the pool at el 534, the upper level port center line was set at el 500 for withdrawal during model simulation. Withdrawal through this port would be required to meet downstream temperature objectives during July of an average year. Two pumpback configurations were tested, pumpback through the withdrawal port and pumpback through the low level flood gate.

Marysville Lake stratification

22. The effects of unsteady operation on Marysville Lake stratification were investigated by operating the hydrodynamic model with the anticipated prototype operation scheme. Changes in the stratification were evaluated by comparing vertical density profiles taken at the end of each prototype week of simulation. As anticipated, these density profiles revealed that the pumpback flow process had a much stronger effect on density stratification than did inflow or withdrawal. Pumped flow establishes a density current that causes mixing with respect to time within a vertical zone of the pool as shown in Figure 4. This same phenomenon was observed in a previous pumped-storage model study and is discussed in detail in Reference 2. This zone of mixing corresponded to the zone of interflow of the pumpback current. The observed pumpback flow process is schematically described in Figure 5.

23. To account for the mixing within the zone of interflow of the pumpback current, a procedure that was developed during the previous

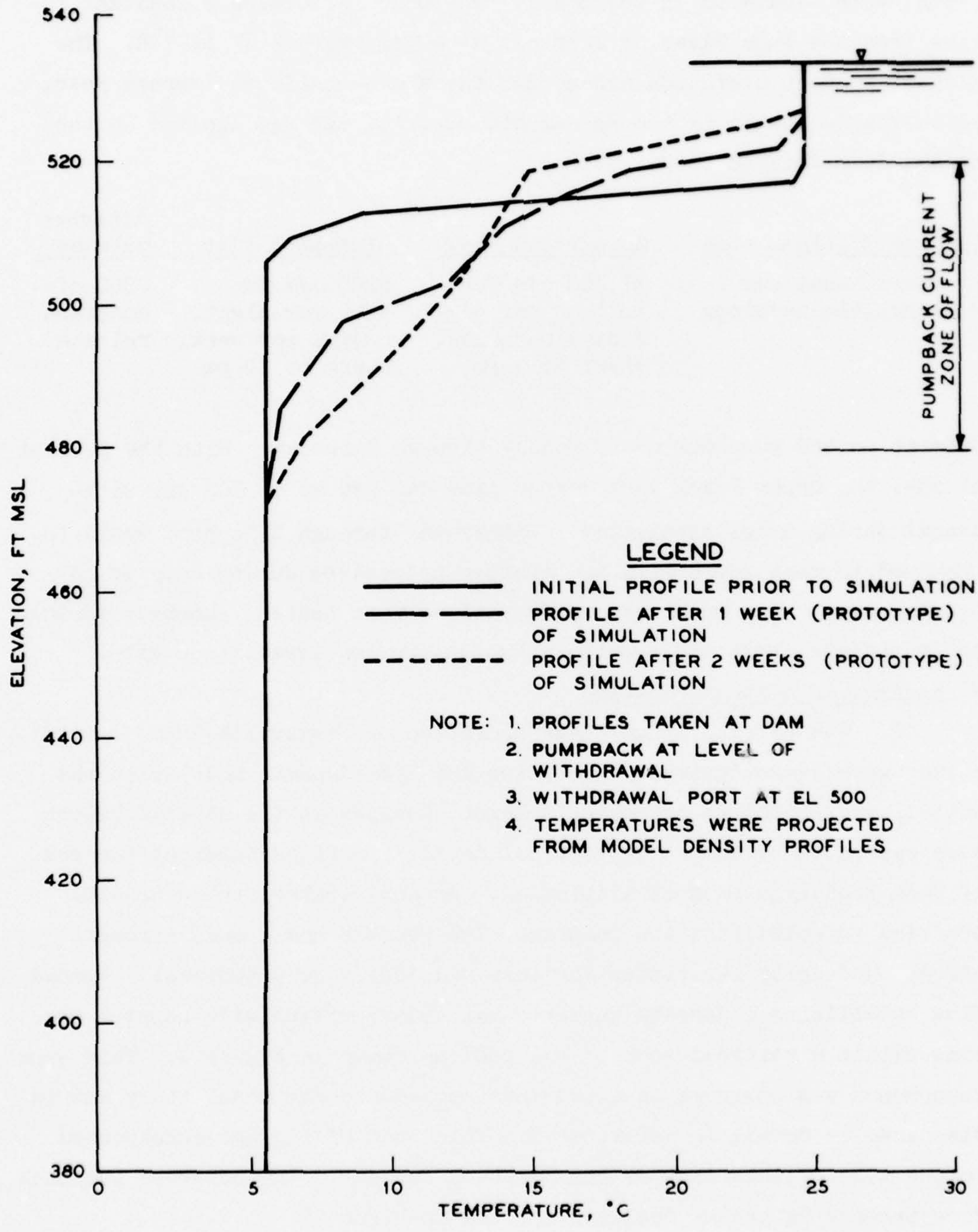


Figure 4. Mixing created by pumpback currents as demonstrated by the physical model

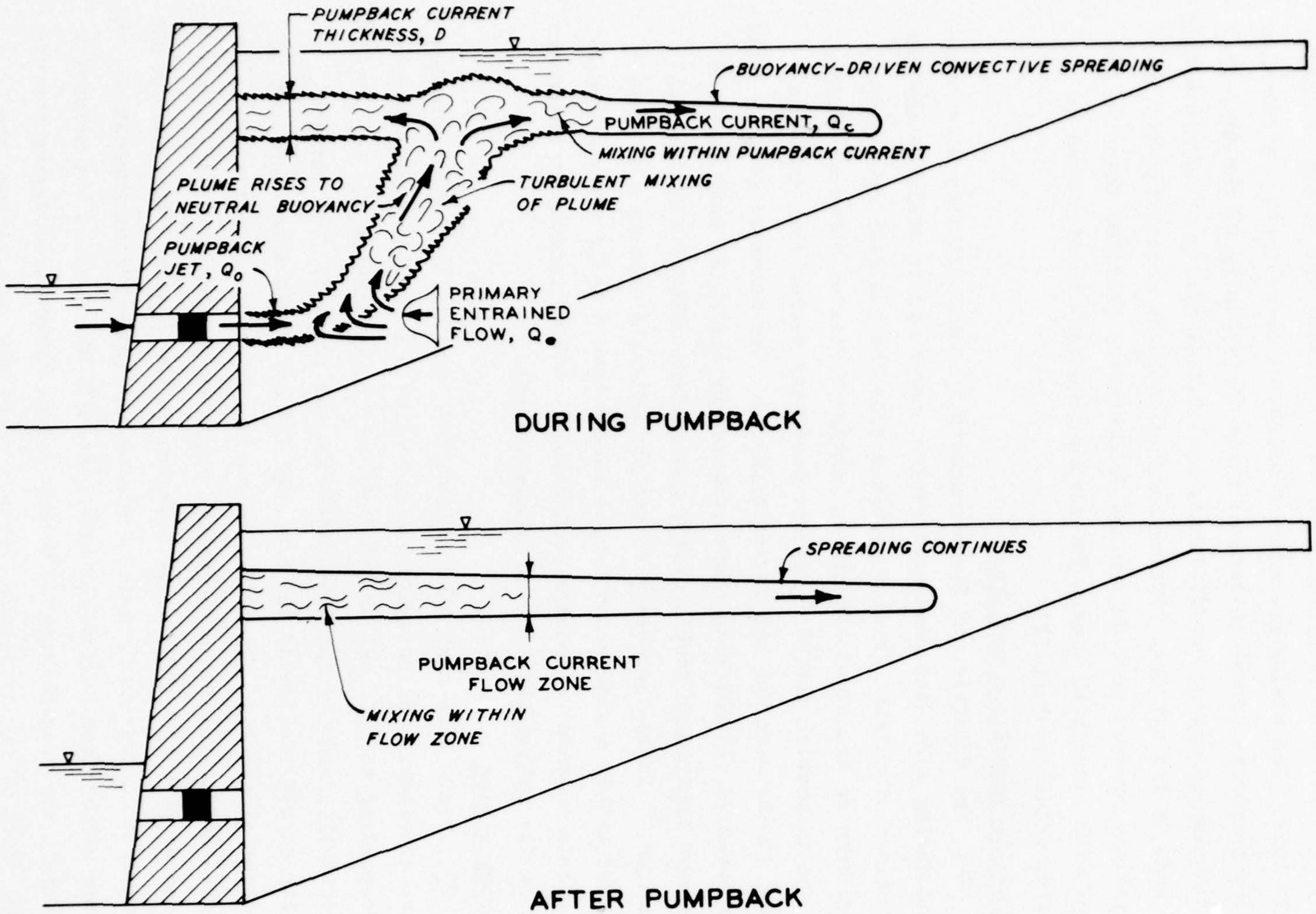


Figure 5. Pumpback characteristics

study[2] was found to be appropriate for describing the effect in Marysville Lake. The mixing procedure consists of three parts: prediction of the pumpback-current thickness, D, in the vicinity of the dam; determination of mixing coefficients; and partial mixing of layers within the zone of the current. Mixing coefficients characteristic of the Marysville project were determined from density profiles taken in the model with respect to time. The mixing technique is discussed in greater detail in Part III.

Marysville generation releases

24. The densities of flows released into the afterbay were monitored during simulated power-generation operations to evaluate whether variations of release density resulted from the unsteady operation. There were no transient effects on release densities observed during any one generation period. Release densities varied some from one period to the next but not during a period. The observed release densities compared closely with those computed by the U. S. Army Engineer Waterways Experiment Station (WES) generalized selective withdrawal technique.[3] It was necessary to use the actual discharge rate that occurred within a generation period rather than a daily average generation rate to make reasonable predictions. Actual generation rates are used in the mathematical model (paragraph 46).

Afterbay mixing

25. Tests were conducted to determine the mixing characteristics of the afterbay. The afterbay was set up with a density stratification corresponding to 23°C and 18°C waters for the epilimnion and hypolimnion, respectively, and the operation schedule was imposed. The vertical density stratification of the afterbay did not exist after one week of prototype simulation. Therefore, stratification of the afterbay is not expected to exist. The afterbay was found to be almost totally mixed at the end of each prototype day. However, it was observed that during the period of a day various stages of mixing existed. During generation, the release waters from Marysville Lake partially mixed with, but primarily displaced, the pregeneration afterbay water, thereby, occupying the upstream reach of the afterbay. Because there was some mixing, the

pumpback water consisted of pregeneration afterbay water and Marysville Lake release water. After the completion of pumpback, the remaining generation water was observed to disperse throughout the afterbay. For numerically modeling the afterbay, this allowed the simplifying assumption that the afterbay is fully mixed at the end of each day.

Pumpback temperature

26. Tests were conducted to determine what volume of pregeneration afterbay water was pumped back with the Marysville release water following a generation period. This information was needed to provide proper simulation of the pumpback temperature and mixing of the residual waters in the afterbay after pumpback. Fluorescent dye, which was mixed with the pregeneration afterbay water, was used to trace the contribution of pregeneration afterbay water in the pumpback flow.

27. The predominant factor influencing the pumpback constituents was considered to be the pumped volume ratio, which is defined as:

$$\text{Pumped volume ratio} = \frac{\text{volume of water pumped back in one day}}{\text{volume of water released during generation in one day}} \qquad (1)$$

To examine a full range of flow conditions, three operation schedules were selected for model testing from the various operations anticipated by SPK. The flows and pumped volume ratios for the conditions tested are presented below.

Generation Flow	Pumpback Flow	Pumped Volume Ratio
36,400 cfs for 1.80 hr per day	1000 cfs for 2.42 hr per day	0.04
37,700 cfs for 3.71 hr per day	8200 cfs for 9 hr per day	0.53
37,400 cfs for 3.28 hr per day	9280 cfs for 9 hr per day	0.68

A constant afterbay release of 2360 cfs was used for each condition. A measurement of initial fluorescent dye concentration in the afterbay was made prior to generation. The generation period was then simulated causing mixing in the afterbay. After generation, pumpback was

initiated. During pumpback, samples of water drawn into the draft tubes were collected and analyzed for fluorescent dye concentration. The average dye concentration of the pumped flow was related to the initial concentration of dye in the afterbay to determine the volume of pregeneration afterbay water pumped back. The ratio of the volume of pregeneration afterbay water pumped back with respect to the total volume of water pumped back in one day was correlated with the pumped volume ratio. A best fit of the data gave the following equation:

$$V_A = V_p(0.004e^{5.80r}) \tag{2}$$

where

V_A = volume of pregeneration afterbay water that is pumped back in one day, acre-ft

V_p = total volume of water that is pumped back in one day, acre-ft

e = natural logarithmic base, 2.7183

r = pumped volume ratio

With a knowledge of V_A, it is possible in the numerical model to determine the pumpback temperature and mix the water remaining in the afterbay after pumpback.

Pumpback entrainment

28. The amount of flow entrained by the pumpback jet was determined from the physical model for both the high- and low-level pumping configurations. Entrained flow is water that is pulled into and mixed with the pumpback jet. The mixture goes into storage in the pool at a density equal to the density of the mixture, thus, creating a pumpback density current. Coefficients of entrainment are necessary for numerical model simulations.

29. Conservation of mass and volume were used to determine the amount of bulk entrainment as follows. From the conservation of mass

$$\rho_c Q_c = \rho_o Q_o + \rho_e Q_e \tag{3}$$

where

ρ_c = average density of pumpback current, g/cc

Q_c = volume flow rate of pumpback current, cfs

ρ_o = density of pumpback jet, g/cc

Q_o = volume flow rate of pumpback jet, cfs

ρ_e = average density of entrained current, g/cc

Q_e = volume flow rate of entrained current, cfs

Also, from the continuity of volume for an incompressible fluid

$$Q_c = Q_o + Q_e \tag{4}$$

Substitution of equation 4 into equation 3 for Q_c yields

$$Q_e = EQ_o \tag{5}$$

where E is the entrainment coefficient and

$$E = \frac{\rho_o - \rho_c}{\rho_c - \rho_e} \tag{6}$$

The value of ρ_e was taken from the initial density profile at the elevation where the maximum contribution of entrainment was observed in the model. Density measurements were taken at the Marysville tailrace and within the pumpback current to obtain ρ_o and ρ_c, respectively.

30. With pumpback through an upper port, E was found to be approximately 0.7 for the conditions tested. The entrainment was observed to occur primarily from the layers of the pool at and immediately above the location of the port. Considerably more entrainment was detected with pumpback through the lower level floodgates. Calculations from density measurements indicated that E was as large as 2.5 to 3.0. To substantiate these values, velocity profiles of the entrained flow were measured.

Assuming uniform flow laterally, the velocity profiles were converted to flow rate, or Q_e. By substitution of Q_e and Q_o into equation 5, E was found to be about 2.5. For pumpback through the floodgate, entrainment occurred from the bottom up to an elevation about 170 ft above the bottom.

Inflow

31. With a constant inflow from the Yuba River of 2288 cfs simulated in the model, the inflow current traveled to the Marysville Dam in a week (prototype time). This travel time indicates that the thermal structure of the lake at the dam should respond in a short time to the effects of inflow. Practically no entrainment due to inflow was observed in the model for the 2288-cfs flow rate. Therefore, the assumption of zero inflow entrainment was used for the numerical simulations.

Topographical effects

32. The ridge upstream of and generally parallel to the dam was observed to influence circulation and mixing in the vicinity of the dam during pumpback through the floodgate. For both pumpback configurations (jet entering the pool through an upper level port or through the low level floodgate), the pumpback current travelled upstream and spread throughout Marysville Lake. For pumpback through an upper level port with the conditions simulated in the physical model (paragraph 21), the current was able to spread over the top of the ridge as it travelled upstream. For pumpback through the floodgate, the plume became neutrally buoyant at an elevation within the water column (el 490-500) that was below many of the ridge peaks. This forced much of the current to travel around Timbuctoo Bend rather than over the ridge. Additionally, the entrained flow, which consisted of water between the bottom and about el 370, was forced to travel around Timbuctoo Bend because of the presence of the ridge. For the low level pumpback, the ridge certainly influenced circulation in the vicinity of the dam, and the flow restriction created by the ridge tended to increase the turbulence and thickness of the pumpback current in the region between the dam and the ridge. The above-mentioned phenomena in addition to the large entrained flow that occurs with the low level pumpback of warm water would cause

some mixing and warming of water in the hypolimnion. If an objective of the project is to conserve cold water reserves for fall releases, then pumpback through the floodgate (accompanying releases through an upper port) could be undesirable and pumpback at the level of withdrawal is recommended.

33. The invert of the channel (el 400) connecting the Dry Creek embayment with the main lake prevents water in the Dry Creek embayment below el 400 from entering the main lake. This reduces the total cold water storage capacity of the lake. To account for this reduction in the numerical model, the volumes of layers below el 400 that are contained in the Dry Creek embayment were subtracted from the total volume of each layer below el 400. Although water below el 400 in the Dry Creek embayment was stagnant, water above el 400 circulated freely. Inflow, pumpback, and withdrawal flows passed to and from the Dry Creek embayment above el 400.

PART III: MATHEMATICAL MODEL DESCRIPTION

34. The internal heat budget in Marysville Lake and the release temperatures downstream of the project and at the confluence of the Yuba and Feather Rivers were predicted using a numerical simulation model. The model used in conjunction with this investigation was previously developed at WES and modified to uniquely describe the thermal characteristics of the Marysville Lake project. During the development of the model, considerable insight has been gained from the research efforts of Bohan and Grace,[3] Clay and Fruh,[4] Edinger and Geyer,[5] Dake and Harleman,[6] and others.

Fundamental Assumptions

35. The Marysville Lake hydrothermal mathematical model provides a procedure for examining the balance of thermal energy imposed on an impoundment. This energy balance and lake hydrodynamic phenomena are used to map vertical profiles of temperature and release temperatures in the time domain. The model includes computational methods for simulating heat transfer at the air-water interface, advective heat due to inflow, outflow, and pumpback processes, and the internal dispersion of thermal energy. The model is conceptually one-dimensional based on the division of the impoundment into discrete horizontal layers of uniform thickness. Assumptions include the following:

- a. Isotherms are parallel to the water surface both laterally and longitudinally.
- b. The water in each discrete layer is isotropic and physically homogeneous.
- c. Internal advection and heat transfer occur only in the vertical direction.
- d. External advection (inflow, outflow, and pumpback) occurs as a uniform distribution within each layer.
- e. Internal dispersion (between layers) of thermal energy is accomplished by a diffusion mechanism that combines the effects of molecular diffusion, turbulent diffusion, and thermal convection.

36. The surface heat exchange, internal mixing, and advection processes are simulated separately and their effects are introduced sequentially at specified time intervals. A simplified flow chart of the mathematical simulation procedure is presented in Figure 6.

Surface Heat Exchange

37. The Marysville Lake mathematical model employs an approach to the evaluation of surface heat transfer developed by Edinger and Geyer.[5] This method formulates equilibrium temperatures and coefficients of surface heat exchange. Equilibrium temperature is defined as that temperature at which the net rate of heat exchange between the water surface and the atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process will occur. The equation describing this relationship is:

$$H = K(E - \theta) \tag{7}$$

where

H = net rate of surface heat transfer, Btu/ft^2/day

K = coefficient of surface heat exchange, Btu/ft^2/day/$^\circ$F

E = equilibrium temperature, $^\circ$F

θ = surface temperature, $^\circ$F

The computation of equilibrium temperature and heat exchange coefficient is based solely on meteorological data as outlined by Edinger, Duttweiler, and Geyer.[7]

38. The net heat exchange at the surface is composed of seven heat exchange processes:

a. Shortwave solar radiation.

b. Reflected shortwave radiation.

c. Long-wave atmospheric radiation.

d. Reflected long-wave radiation.

e. Heat transfer due to conduction.

f. Back radiation from the water surface.

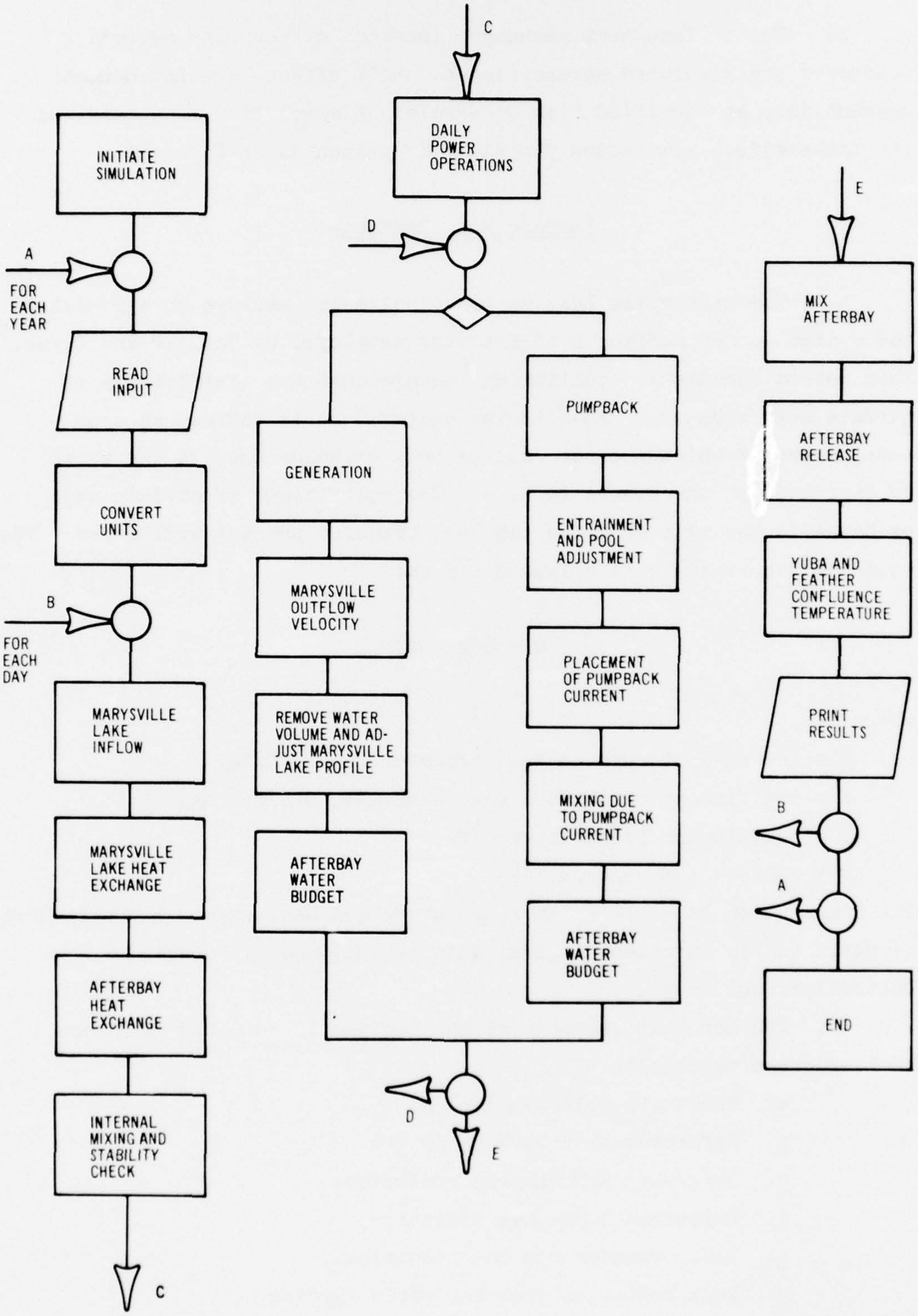


Figure 6. Mathematical model flow chart

g. Heat loss due to evaporation.

For every day of meteorological data, the seven heat exchange terms can be evaluated and the net heat exchange expressed in terms of an equilibrium temperature and an exchange coefficient.

39. All of the surface heat exchange processes, with the exception of shortwave radiation, affect only approximately the top few feet of the lake. Shortwave radiation penetrates the water surface and increases the temperature at greater depths. Based on laboratory investigations, Dake and Harleman[6] have suggested an exponential decay with depth for describing the heat flux due to shortwave penetration.

40. The surface heat exchange concepts are implemented in the model by the exponential penetration of a percentage of the incoming shortwave radiation and the placement of the effect of all other sources of surface heat exchange into the surface layer. This procedure can be expressed mathematically by the following two equations:

$$H_s = K(E - \Theta) - (1 - \beta)S \tag{8}$$

$$H_i = (1 - \beta)Se^{-\lambda z_i} \tag{9}$$

where

H_s = heat transfer rate into or out of surface layer, Btu/ft^2/day

β = shortwave radiation absorbed in the surface layer, percent

S = total incoming shortwave radiation rate, Btu/ft^2/day

H_i = rate of heat absorbed in layer i , Btu/ft^2/day

e = natural logarithmic base (2.7183)

λ = heat absorption coefficient, ft^{-1}

z_i = depth below surface, ft

41. Equations 8 and 9 are applied to the Marysville Lake temperature profile once during each one-day time step. The net heat exchange rate into each layer is computed and converted to a temperature change. The temperature changes are used to determine an updated temperature profile for Marysville Lake. Numerically, the Marysville afterbay is mixed at the end of each daily time step. Thus, surface heat exchange

in the afterbay is effected by converting the total heat exchange rate as indicated in equation 7 to a temperature change. The temperature change is then added to the existing afterbay temperature once during each one-day time step.

Inflow

42. The process of inflow into a lake is simulated in the mathematical model by the placement of inflow quantity and quality at that layer in which the density of the lake corresponds most nearly to the density of the inflow. Although not indicated in this study, research efforts and physical model studies at WES have shown that entrainment-induced density currents can exist which flow upstream along the surface into the turbulent mixing zone caused by the inflow.

43. When it exists, entrainment is implemented in the model by augmenting the inflow quantity with a volume from the surface layer. The volume from the surface layer is generally expressed as a percentage of the inflow quantity. Characteristics of inflow and the entrained flow are averaged, and mixed values of density, temperature, and other water-quality parameters are determined. The mixed density is used to determine placement of the total quantity and mixed quality. Simulation of the inflow process displaces upward a volume equal to the total inflow quantity. This upward displacement is reflected in the model by an increase in the water surface. A corresponding decrease in water surface occurs as a result of the outflow simulation process.

Internal Dispersion

44. The internal dispersion process is represented by an internal mixing scheme based on a simple diffusion analogy. Internal mixing transfers heat and other water-quality constituents between adjacent layers. The magnitude of the transfer between two layers is a percentage of the total transfer required to completely mix the two layers. This percentage is a mixing coefficient which is defined for every

layer. Data input includes values of the mixing coefficient at the top and at the bottom of the lake. An exponential fit between the two extreme values is used to determine the appropriate coefficient for each layer.

Outflow

45. The outflow component of the model incorporates the selective-withdrawal techniques for orifice flow developed at WES.[3] Additionally, the selective-withdrawal description was analyzed to include the appropriate application to simultaneous releases from multiple horizontal ports (Appendix B). Transcendental equations defining the location of zero-velocity limits are solved with a half-interval search method. The location of the zero-velocity limits is functionally dependent on the configuration of the withdrawal device, release flow rate, and density structure within the lake. With knowledge of the limits of the withdrawal zone, the velocity profile due to outflow can be determined. The flow from each layer is then computed as the product of the velocity in the layer and the width and thickness of the layer. A flow-weighted average is applied to the temperature profile to determine the value of the release temperature for each flow condition. When the port to be used for outflow is not specified, such as in a predictive mode, the model compares target temperatures and the simulated thermal profiles to select the ports to be used for withdrawal.

Operation Schedules

46. Because the generation and pumpback flows change markedly in a day and the rate of these flows affects withdrawal and pumpback characteristics, it was not adequate to use daily average flows to accurately simulate generation and pumpback operations. Daily average flow routings usually are quite adequate for less dynamic reservoirs, such as water supply and flood control projects. For this model, the planned generation and pumpback flow rates and durations (in hours) are used

rather than daily averages. The model can handle up to twelve different flow conditions within a day. The Julian day number, the modes of operation (generation or pumpback), flow rates, durations of flow, and elevation of the pumpback device are input for each day that a change in the operation schedule occurs.

Marysville Afterbay

47. The afterbay is modeled numerically by maintaining heat and water budgets. The afterbay is fully mixed at the end of each daily time step. This assumption is supported by physical model observations and densimetric Froude number[8] calculations, and it allows further simplifying assumptions to be made with respect to advection and heat exchange in the afterbay. The daily surface heat exchange is accomplished by applying equation 7 to the afterbay surface area that exists at the beginning of each daily time step. Once during each day of simulation, the volume of water in the lake is adjusted to sequentially account for (a) Marysville Lake generation volume that is not pumped back, (b) pregeneration afterbay volume that is pumped back, and (c) afterbay volume that is released downstream. The net contributions of volume from Marysville Lake at the respective temperatures are added to the afterbay volume producing a mixed value of temperature. This mixed temperature is the afterbay release temperature for that day of simulation. Figure 7 helps describe the approach followed in modeling the afterbay.

Pumpback Temperature and Entrainment

48. For the numerical simulations, it is necessary to define the temperature of the flow pumped from the afterbay to the lake. If generation does not occur on the same day that there is pumpback, then the temperature of the afterbay water constitutes the pumped flow temperature. However, if generation occurs prior to pumpback on the same day, then the pumped temperature can result from a mixture of pregeneration

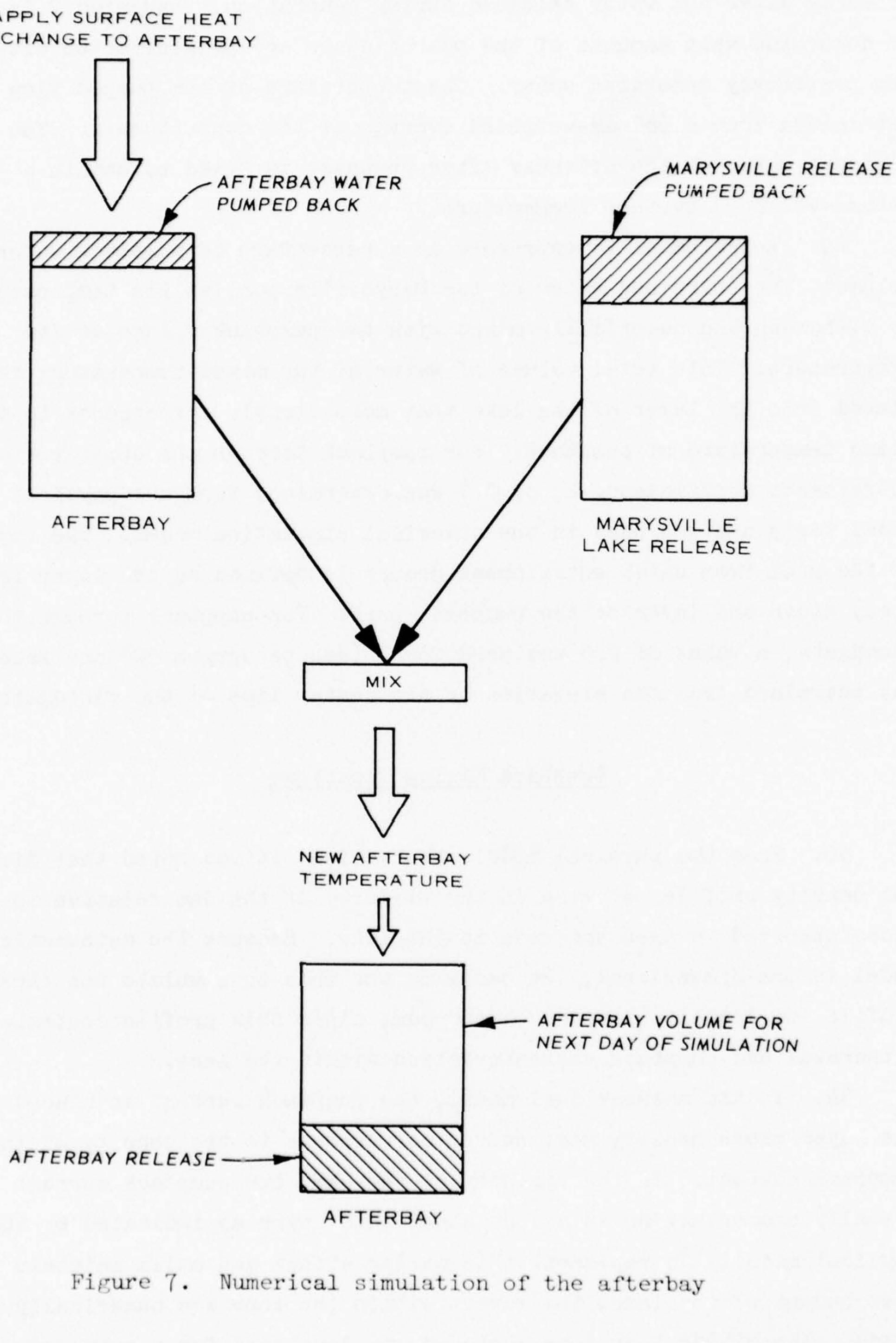


Figure 7. Numerical simulation of the afterbay

afterbay water and water released during generation. Equation 2 is used to determine what amounts of the pumped water are pregeneration afterbay and previously generated water. The temperature of the pumped flow is determined from a volume-weighted average of the constituents. The residual water of the afterbay after pumpback is mixed to obtain a volume-weighted average temperature.

49. Entrainment is expressed as a percentage of pumpback water volume. The entrained water of the Marysville pool at its temperature is withdrawn and numerically mixed with the pumpback volume at its temperature. This total volume of water at the mixed temperature is placed into the layer of the lake that most closely corresponds to the mixed temperature of pumpback. For pumpback through the upper ports, an entrainment coefficient, E, of 0.7 was determined from the physical model tests and was used in the numerical simulation model. The layer of the pool from which entrainment occurs is defined as the layer immediately above the layer of the pumpback port. For pumpback through the floodgate, a value of 2.5 was used for E (see paragraph 30) and water was entrained from the elevation of the center line of the floodgate.

Pumpback Mixing Technique

50. From the physical model observations it was noted that different density profiles existed in the vicinity of the dam relative to those observed further upstream in the lake. Because the mathematical model is one-dimensional, the decision was made to simulate the thermal profile immediately upstream of the dam, since this profile controls the withdrawal and pumpback characteristics within the lake.

51. In the mathematical model, the pumpback current is placed in the layer whose density most nearly corresponds to the density of the pumpback current. In the vicinity of the dam, the pumpback current actually causes mixing in a zone about this layer as indicated by the physical model. To represent this mixing effect and still maintain the heat budget of the lake, the layers within the zone are numerically mixed. The mixing technique employed was developed for a previous

pumped-storage model study.[2] The technique is based on the concept of a portion of each of the layers in the pumpback zone being removed, mixed together, returning the mixed water to the layers in the zone, and then mixing within each layer. The portion of water removed and mixed from each layer is computed by multiplying a mixing coefficient (a number between 0 and 1) times the volume of the layer. The mixing coefficients were determined using data from the physical model. Density profiles were measured in the physical model before and after pumpback operations. By analyzing the difference in these profiles, it was possible to determine the mixing coefficients necessary for application to the initial profile so that the final profile could be obtained.

52. The thickness, D (ft), of the pumpback current, which is the same as the above-mentioned mixing zone, is calculated from the equation

$$D = 4.1\left(\frac{Q_c}{W\sqrt{\frac{\Delta\rho}{\rho_c}\,g}}\right)^{2/3} \tag{10}$$

where

Q_c = volumetric flow rate of the pumpback current (includes entrainment), cfs

W = average reservoir width at the elevation of the current in the vicinity of the dam, ft

$\Delta\rho$ = density difference of the epilimnion and hypolimnion, g/cc

ρ_c = average density of the pumpback current, g/cc

This equation was developed from the previous model study.[2]

53. Mixing coefficients were computed for the pumpback operation tests conducted in the physical model (paragraph 21). Analysis of the mixing coefficients revealed that they had characteristics similar to the mixing coefficients developed in the previous model study.[2] Based on those results, plus the results from the Marysville Lake pumpback operation tests, an equation was developed to predict the mixing coefficient in a layer as a function of the distance of that layer from the pumpback current inflow layer

$$\eta_i = A\, e^{-BX_i} \tag{11}$$

where

η_i = mixing coefficient

A = 0.1675

B = 0.118

X_i = distance from the pumpback current inflow layer to layer i

i = layer

54. To represent the pumpback mixing technique within the mathematical model, the following sequence of computational steps is employed. The thickness of the zone affected by the pumpback current is computed and this zone is distributed about the layer of pumpback placement. The mixing coefficient for each layer in the zone is computed by equation 11, the amount of each layer to be mixed is computed as the product of the mixing coefficient and the layer volume, and the portions from the layers are mixed together. The mixed water is returned to the layers, and each layer is individually mixed.

Downstream Temperature Routing

55. Afterbay temperatures were routed downstream using Edinger's[5] temperature model for a well mixed stream with uniform depth and velocity:

$$T_x = (T_o - E)e^{(-KX/\gamma c_p vd)} + E \tag{12}$$

where

T_x = temperature at downstream end of reach, ^oF

T_o = temperature at upstream end of reach, ^oF

E = equilibrium temperature, ^oF

K = surface heat exchange coefficient, Btu/ft^2/day/^oF

X = reach length, ft

γ = specific weight of water, 62.4 lb/ft^3

c_p = specific heat of water, 1 Btu/lb/°F

d = uniform stream depth, ft

v = uniform stream velocity, ft/day

56. Routings were accomplished in two steps due to projected irrigation withdrawals at Daguerre Point. Afterbay temperatures were routed 3.3 miles to Daguerre Point with a velocity and depth corresponding to the afterbay release flow. The temperature computed for Daguerre Point was then routed 9.2 miles to the mouth of the Yuba River with a velocity and depth corresponding to the flow remaining after the diversion. Equilibrium temperatures and surface heat exchange coefficients were the same as those used for Marysville Lake and afterbay. Velocity-depth products were computed from the relationship

$$vd = 2730Q^{0.7036} \tag{13}$$

where

vd = velocity times depth, ft^2/day

Q = flow rate, cfs

This relationship was developed by SPK from fitting observed flow data for water year 1975 with values of vd computed from equation 12 using observed water temperature and meteorological data for 1975.

PART IV: MATHEMATICAL SIMULATIONS

Development of Data

57. At the request of SPK, three hydrologic years were used for the simulations: 1934, the driest year in the period of record; 1942, the wettest year in the period of record; and 1962, an average year for the period of record. Meteorological data from Beale Air Force Base, located about 7 miles south of the project, exist from 1960 to the present. Equilibrium temperatures were computed from these meteorological data for years 1960 through 1970. These equilibrium temperatures were analyzed to determine hot, 1967; cold, 1963; and average, 1962, meteorological years. These hydrologic and meteorologic conditions were combined to form three study years composed as follows:

Study Year 1	1962	Hydrology (average)
	1962	Meteorology (average)
Study Year 2	1934	Hydrology (dry)
	1967	Meteorology (hot)
Study Year 3	1942	Hydrology (wet)
	1963	Meteorology (cold)

These three combinations of hydrologic and meteorologic data were analyzed in the initial simulations. The hydrologic data for the three study years are shown in Table 1.

58. Based on projected operations studies, mean monthly inflows and afterbay releases were provided by SPK. Since daily input is required by the mathematical model, the mean monthly value was used for each day of simulation. SPK also provided the daily operational schedules, Table 2 (generation and pumpback flow rates and durations), for the three selected hydrologic years (except that there is no pumpback for Study Year 2).

59. As discussed in the preliminary report (Appendix A), a flow weighted average of New Bullard's Bar Reservoir release flow temperatures and South Yuba River temperatures was used to represent the inflow temperatures to Marysville Lake for all three study years.

Although other inflows to the project will exist, they were not considered in the determination of inflow temperatures since the New Bullard's Bar releases and South Yuba River flow constitute the majority of the total project inflow. Since the preliminary simulations showed Marysville Lake to be relatively insensitive to variations of input temperatures used, it was believed that the use of one set of inflow temperatures for all three study years was warranted. These flow temperatures are shown in Plate A1.

60. Temperature objectives at the confluence of the Yuba and Feather Rivers were furnished by SPK. The objectives consisted of an upper and lower limit on stream temperature as functions of time through the year. The objectives (identified as "Downstream Objectives" on the various plates) are shown on all the plots of predicted temperature at the release, afterbay, and confluence ("Downstream").

Initial Simulations and Model Calibration

61. A preliminary report containing the initial mathematical simulations was furnished SPK in December 1975. The purposes of the initial simulations were to (a) approximate the feasibility of the project to meet downstream temperature objectives, (b) determine port locations that allow the project to meet the objectives, (c) permit comparison with the final numerical simulations to assess the benefits of the physical model investigation and mathematical model refinements, and (d) allow determination of proper coefficients by model calibration. That preliminary report is included as Appendix A.

62. The report of December 1975 contained only simulations for 1962 hydrologic and meteorologic conditions. Subsequently, SPK requested that initial simulations be performed for hydrologic years 1934 and 1942. Both of these hydrologic years were simulated with three years of meteorologic data, 1962, 1963, and 1967. These simulations required five selective withdrawal levels and a floodgate to meet temperature objectives. The results were furnished SPK during April 1976. In May 1976, SPK furnished WES with revised routings based on a

new operation study, and the initial simulations were again performed. Each of the hydrologic years 1934, 1942, and 1962 was simulated with all three meteorologic years, 1962, 1963, and 1967. These results were furnished SPK during June 1976.

63. As discussed previously, the mathematical model requires the determination of coefficients of surface heat exchange distribution and internal mixing. The preliminary report describes the calibration of the model for the initial simulations. The following coefficients were determined from that analysis.

$$\beta = 0.95$$

$$\lambda = 0.3$$

$$\alpha_1 = 0.1$$

$$\alpha_2 = 0.1$$

where

β = percentage of incoming shortwave radiation absorbed in the surface layer

λ = absorption coefficient

α_1 = mixing coefficient at surface

α_2 = mixing coefficient at bottom

As discussed in Appendix A, the value of β was necessarily large to account for the use of 10-ft vertical layers in the mathematical model.

64. Following the initial simulations, the surface heat exchange portion of the mathematical model was modified so that the β coefficient is applied to the upper 2 ft of the lake, regardless of the vertical layer size. This allows values for β and λ that can be more easily correlated to light transparency data. Additionally, the lake was divided into 5-ft vertical layers to yield greater detail in the model results. Incorporating these changes, the mathematical model was recalibrated against the original calibration runs and data for 1976 on light transparency and thermal profiles at New Bullard's Bar

and Englebright Reservoirs. These data were provided by SPK. The values of the coefficients from this recalibration were:

$$\beta = 0.35$$

$$\lambda = 0.12$$

$$\alpha_1 = 0.1$$

$$\alpha_2 = 0.1$$

Predicted thermal profiles at Marysville Lake for 1962 hydrologic and meteorologic data and observed thermal profiles at New Bullard's Bar Lake for 1975 and 1976 are shown in Plate 1. The predicted profiles at Marysville Lake were obtained by simulating the lake considering no pumpback flow and water being released only from the highest available port. Comparison of the profiles in Plate 1 shows that the predicted Marysville Lake profiles have a similar shape and have similar surface and bottom temperature ranges to the observed New Bullard's Bar Lake profiles.

Final Simulations

65. Mathematical simulations were conducted for all three study years for two pumpback conditions. These conditions were pumpback at the bottom floodgate and pumpback at the level of withdrawal. These simulations were first conducted with the mean target temperatures at the confluence of the Yuba and Feather Rivers as the target release temperatures for Marysville Lake. The predicted downstream temperatures were not acceptable, although this approach had been used in the initial simulations (Appendix A) and yielded satisfactory results. With the revised mathematical model, the effect of the afterbay on the downstream temperatures was more realistically described. The effect of the reregulation pool is such that downstream temperature objectives must be anticipated. An operational change in Marysville Lake must be made with sufficient lead time to produce the desired downstream temperature

at the desired time. Based on the first set of simulations, revised target release temperatures for Marysville Lake were determined so that the resultant downstream temperatures were within the range of desired downstream target temperatures. The results of all final simulations are shown on the following plates:

- Pumpback at the Bottom
  - Predicted In-Lake Profiles
    - Study Year 1 - Plate 2
    - Study Year 2 - Plate 3 no pumpback
    - Study Year 3 - Plate 4
  - Predicted Release, Afterbay, and Downstream Temperatures
    - Study Year 1 - Plate 5
    - Study Year 2 - Plate 6 no pumpback
    - Study Year 3 - Plate 7
- Pumpback at the Level of Withdrawal
  - Predicted In-Lake Profiles
    - Study Year 1 - Plate 8
    - Study Year 2 - same as Plate 3 since there is no pumpback
    - Study Year 3 - Plate 9
  - Predicted Release, Afterbay, and Downstream Temperatures
    - Study Year 1 - Plate 10
    - Study Year 2 - same as Plate 6 since there is no pumpback
    - Study Year 3 - Plate 11

Although blending of flow from multiple vertical outlets to achieve temperature objectives was used in the initial study and can be quite effective, application to a project such as this could be impractical from an operations view. Therefore, these simulations were conducted assuming that releases from all six turbines occur from the same withdrawal level (no blending).

PART V: DISCUSSION

66. The results of the final simulations indicate that the Marysville Lake Project can meet temperature objectives at the Yuba and Feather Rivers confluence. Predicted downstream temperatures were within the band of target temperatures, with only a few exceptions, for all three study years and for both pumpback conditions studied. These three study years represent a broad range of hydrologic and meteorologic conditions. Because release temperatures can change between Marysville Lake and the confluence of the Yuba and Feather Rivers, different release target temperatures had to be established in anticipation of the temperature change. Release temperatures from Marysville Lake can be altered to meet the downstream objectives at the confluence of the Yuba and Feather Rivers, as demonstrated from the fact that downstream temperatures can be moved about within the objective temperature band without blending of withdrawal flows. This again indicates the ability of the project to satisfy objective temperature criteria. At this stage of the project planning, it is felt that to demonstrate the temperatures of the downstream releases would be within an acceptable range should be sufficient. At a later stage, the withdrawal structure design and reservoir operation can be refined to satisfy more stringent downstream temperature objectives, if desired.

67. Since both pumpback conditions studied resulted in satisfying downstream temperature objectives, the difference in pumpback at the bottom or at the level of withdrawal can best be assessed by analysis of the predicted in-lake profiles. As could be expected, the effect of pumpback at the bottom is predominant in the lower portion of the lake while pumpback at the level of withdrawal primarily affected only the upper levels. The pumpback of water at the bottom will cause considerable warming in the hypolimnion and reduction of cold water reserves. It should also be noted that the results of the physical model indicated that more mixing within the lake was induced by pumpback at the bottom than by pumpback at the level of withdrawal.

68. A sensitivity analysis was conducted to determine how much

effect on release temperatures a significant error in the entrainment coefficient E would have for pumpback through the floodgate (at the bottom). Because considerable mixing occurred in the hypolimnion for this pumpback configuration and there was some difficulty in determining E, this analysis was necessary to assess the reliability of the results. To determine the impact of E on release temperatures, Study Year 1 was simulated with all conditions (pumpback at the bottom, port selection, flows, etc.) held constant except the value of E which was changed from 2.5 to 5.0. The effects of E on release temperatures from Marysville Lake and downstream temperatures are presented in Plate 12. The dashed-line circle represents a base condition of release temperature computed by the numerical model with $E = 2.5$. The solid line plots the deviation in temperature from the base condition as a result of the perturbation ($E = 5.0$). The base and perturbed results are plotted throughout the cycle of one year (360° = 1 year) starting on 1 January positioned at the scaled axis and rotating counterclockwise. The results indicate that this variation in E increased the Marysville Lake release temperature by a maximum of 1.5°C and the downstream temperature by a maximum of 0.75°C (Plate 12). The temperature increase was realized only during the last quarter of the year when releases were made from the floodgate. The small variation in downstream temperatures indicates that the downstream temperature routings are not very sensitive to E and that confidence in the prediction can be maintained even with a large error in the E value.

69. The physical model provided valuable understanding of the mixing characteristics within Marysville Lake and afterbay. Results from the physical model tests were used to modify the mathematical model. These modifications described the effects of the generation and pumpback operations on the density structure within Marysville Lake. Results were also used to describe the proportions of previous generation water and afterbay water that composed the pumpback flow. This allowed proper simulation of the pumpback temperature and mixing of residual water in the afterbay.

70. The results of the final simulations for 1962 (Plates 2 and 5)

with pumpback at the bottom can be compared with the initial simulation results shown in Appendix A. The predicted thermal profiles within the lake are similar even though the entrainment by the pumpback jet was 2.5 times greater in the final simulations than it was in the initial simulations. This is because in both cases the pumpback current was placed into the region of the lake below the thermocline where temperature differences are small and changes in the thermal structure would not be great. Although the final and initial predicted downstream temperatures are similar, the target release temperatures for Marysville Lake to achieve those downstream temperatures were quite different. Also the release and afterbay temperatures are different in the initial and final simulations. In the final simulations, the effect of the afterbay is properly accounted for, and the results show that Marysville Lake must be operated to complement or compensate for the afterbay effect (paragraph 65) in order to achieve the desired downstream temperatures. Certainly, the final mathematical model more realistically describes the physical situation than the initial mathematical model did and should serve as an excellent tool for design of the withdrawal structure.

71. All port locations were used by the mathematical model during the final simulations. The port operation schemes used in the simulations are described at the top of the predicted release temperature plots of Plates 5, 6, 7, 10, and 11. A summary of the ports used for each study year and pumpback condition follows:

	Study Year	Location of Pumpback	Ports Used
1	1962 Hydrology	Withdrawal level	2, 3, 6
	1962 Meteorology	Bottom	2, 3, 6
2	1934 Hydrology	No pumpback	4, 5, 6
	1967 Meteorology		
3	1942 Hydrology	Withdrawal level	1, 2, 4*, 5*, 6
	1963 Meteorology	Bottom	1, 2, 6

* Ports 4 and 5 were used for very short periods and were not necessary for this case.

The port numbers represent the following port locations:

Port	Center-Line El
1	540
2	500
3	440
4	375
5	350
6 (floodgate)	219

From these results it appears that port 5 could possibly be eliminated. At least four ports and a floodgate were necessary because of the large fluctuation in pool level (fluctuates from el 429 to 560 over the three years studied) that occurs over the three study years. With less fluctuation in pool level, the temperature objectives could be satisfied with fewer ports. Throughout this study, port 6 has been referred to as a floodgate. Because the flow capacity of all ports was sufficiently large to handle all outflows simulated, it was not necessary to operate port 6 as a floodgate to release large flows. Therefore, port 6 can be considered a low level withdrawal port rather than a floodgate.

72. It should be emphasized that the port locations used in this study are not the only outlet locations which could be used to satisfy temperature objectives. For example, with a pool level that fluctuates substantially, it could be difficult at times to meet warm water objectives with fixed ports. Movable ports or weirs may be more effective in achieving temperature objectives. The mathematical model in conjunction with the physical model can be used in the design phase of the project to evaluate ports, weirs, and combinations of ports and weirs that would satisfy the temperature objectives. Selection of the final design could then be made considering economics, hydraulics, and operational factors.

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Table 1

Hydrologic Input Data, Hydrologic Years 1962, 1934, and 1942

Year	Month	Inflow, cfs per day	Afterbay Release, cfs per day	Irrigation Withdrawal at Daguerre Point, cfs per day
1962	Jan	1449	1434	0
	Feb	3384	1798	0
	Mar	2247	1045	50
	Apr	2237	2172	310
	May	2136	2182	800
	Jun	2364	2424	1000
	Jul	2288	2273	1130
	Aug	1774	1843	1030
	Sep	1283	1343	800
	Oct	4894	4975	360
	Nov	1010	2020	0
	Dec	2061	1985	0
1934	Jan	1773	1758	0
	Feb	2081	2076	0
	Mar	1924	1924	50
	Apr	1434	1450	340
	May	1323	1485	800
	Jun	1308	1348	840
	Jul	1141	1444	930
	Aug	1051	1374	860
	Sep	828	1187	690
	Oct	753	1020	340
	Nov	707	707	0
	Dec	631	682	0
1942	Jan	5722	5551	0
	Feb	6758	6394	0
	Mar	2556	1111	50
	Apr	4793	2924	310
	May	4672	4404	800
	Jun	3788	3788	1000
	Jul	3091	3056	1130
	Aug	1717	1793	1130
	Sep	1258	2929	800
	Oct	995	2040	400
	Nov	742	1753	0
	Dec	2177	2096	0

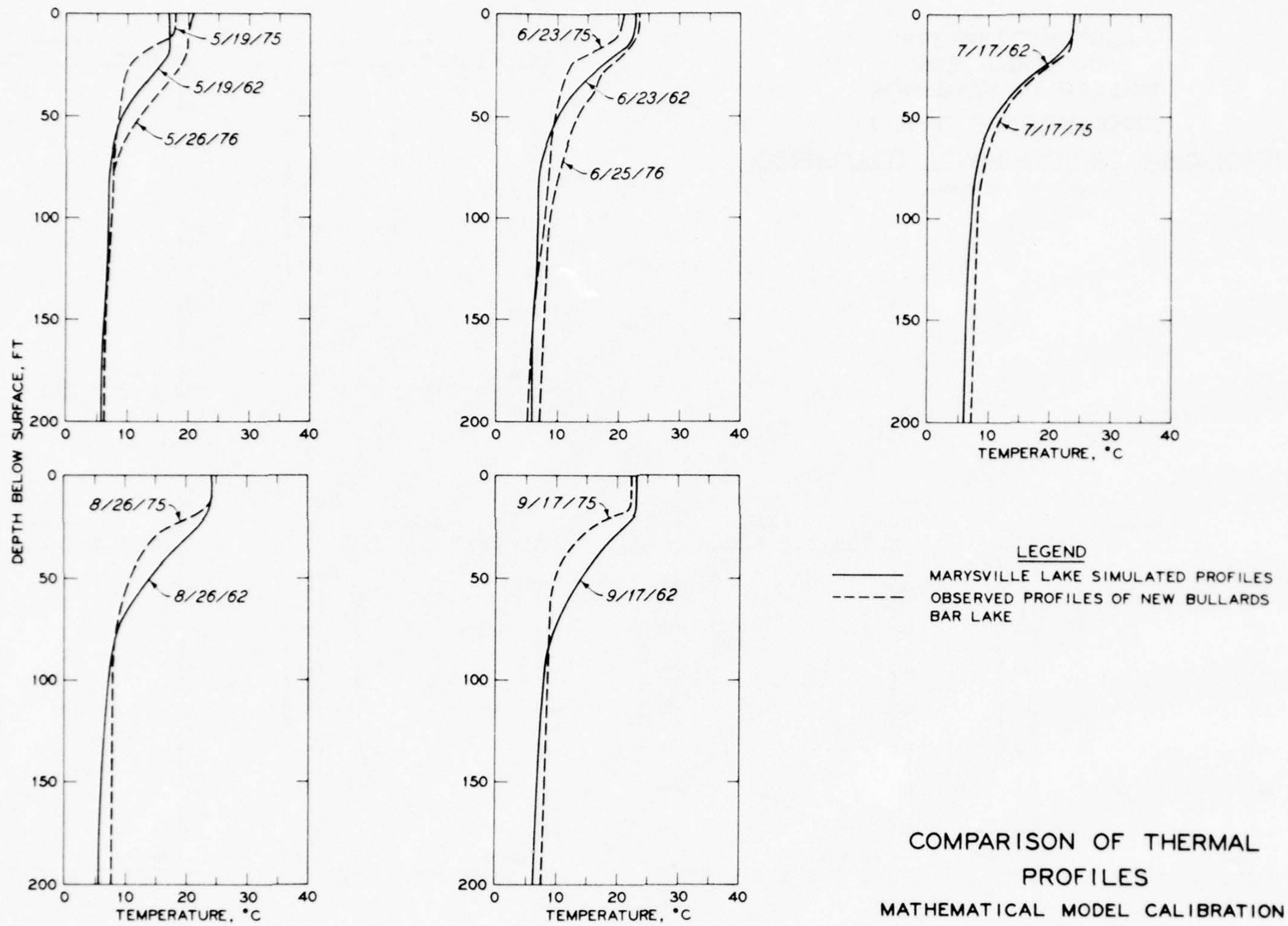
Table 2

Operation Schedule, Hydrologic Years

1962, 1934, and 1942

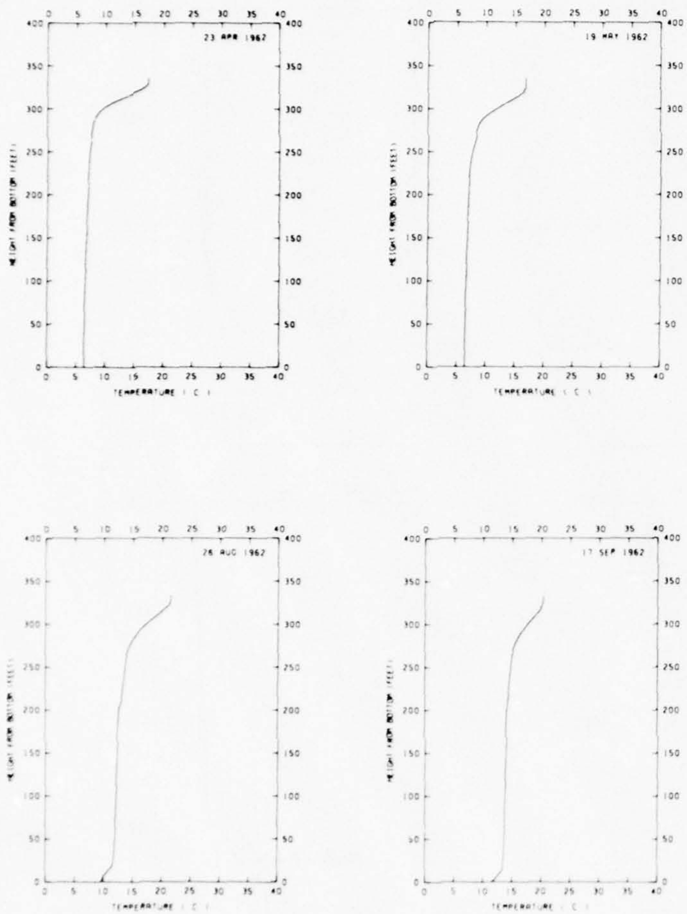
Year	Month	Generation Rate, cfs	Generation Duration, hr per day	Pumpback Rate, cfs	Pumpback Duration, hr per day
1962	Jan	39,800	1.68	2960	9.00
	Feb	38,900	1.88	2560	9.00
	Mar	36,900	1.73	3830	9.00
	Apr	36,400	1.80	1000	2.42
	May	36,500	1.74	1000	2.42
	Jun	36,900	2.33	2020	9.00
	Jul	37,700	3.71	8200	9.00
	Aug	37,500	3.74	9860	9.00
	Sep	37,400	3.28	9280	9.00
	Oct	38,300	3.63	0	0
	Nov	37,500	1.78	1140	9.00
	Dec	38,100	1.71	1000	7.62
1934	Jan	43,200	1.14	No pumpback for this study year	
	Feb	43,000	1.35		
	Mar	43,200	1.25		
	Apr	43,500	0.93		
	May	43,500	0.95		
	Jun	43,000	0.88		
	Jul	42,600	0.95		
	Aug	42,100	0.91		
	Sep	41,300	0.80		
	Oct	41,000	0.70		
	Nov	40,800	0.48		
	Dec	40,800	0.47		
1942	Jan	39,800	3.90	0	0
	Feb	39,900	4.48	0	0
	Mar	36,500	1.73	3580	9.00
	Apr	35,400	2.40	0	0
	May	34,900	3.53	0	0
	Jun	34,500	3.07	0	0
	Jul	34,800	3.83	4940	9.00
	Aug	34,700	3.82	9170	9.00
	Sep	35,700	3.33	3750	9.00
	Oct	36,500	2.26	2840	9.00
	Nov	37,500	1.78	1980	9.00
	Dec	38,100	1.71	1000	4.48

Note: No generation or pumpback on Sundays.



COMPARISON OF THERMAL PROFILES

MATHEMATICAL MODEL CALIBRATION



MARYSVILLE LAKE

COMPUTED TEMPERATURE PROFILES

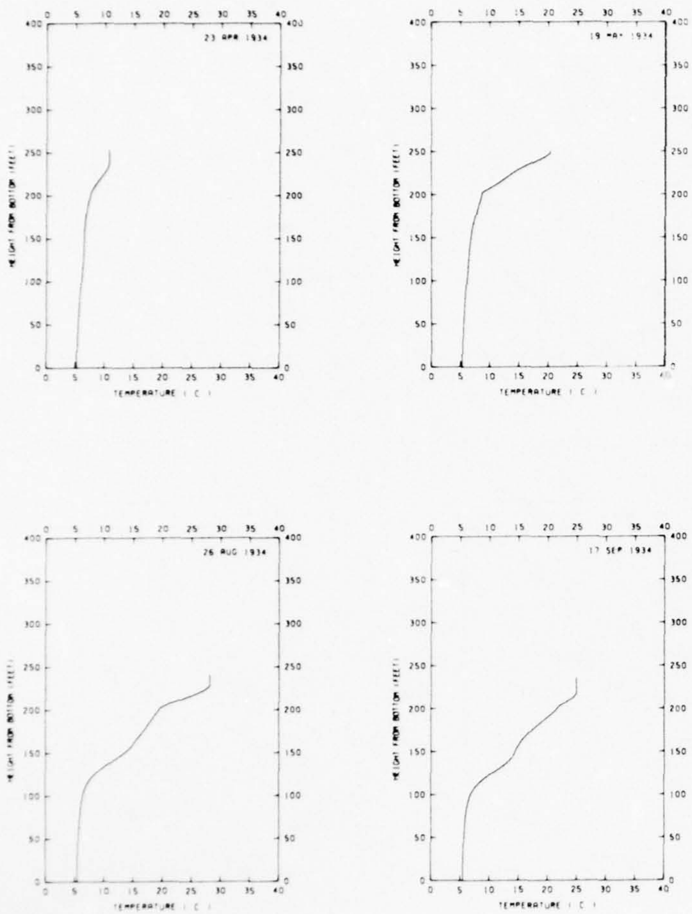
FINAL SIMULATIONS

PUMPBACK AT BOTTOM

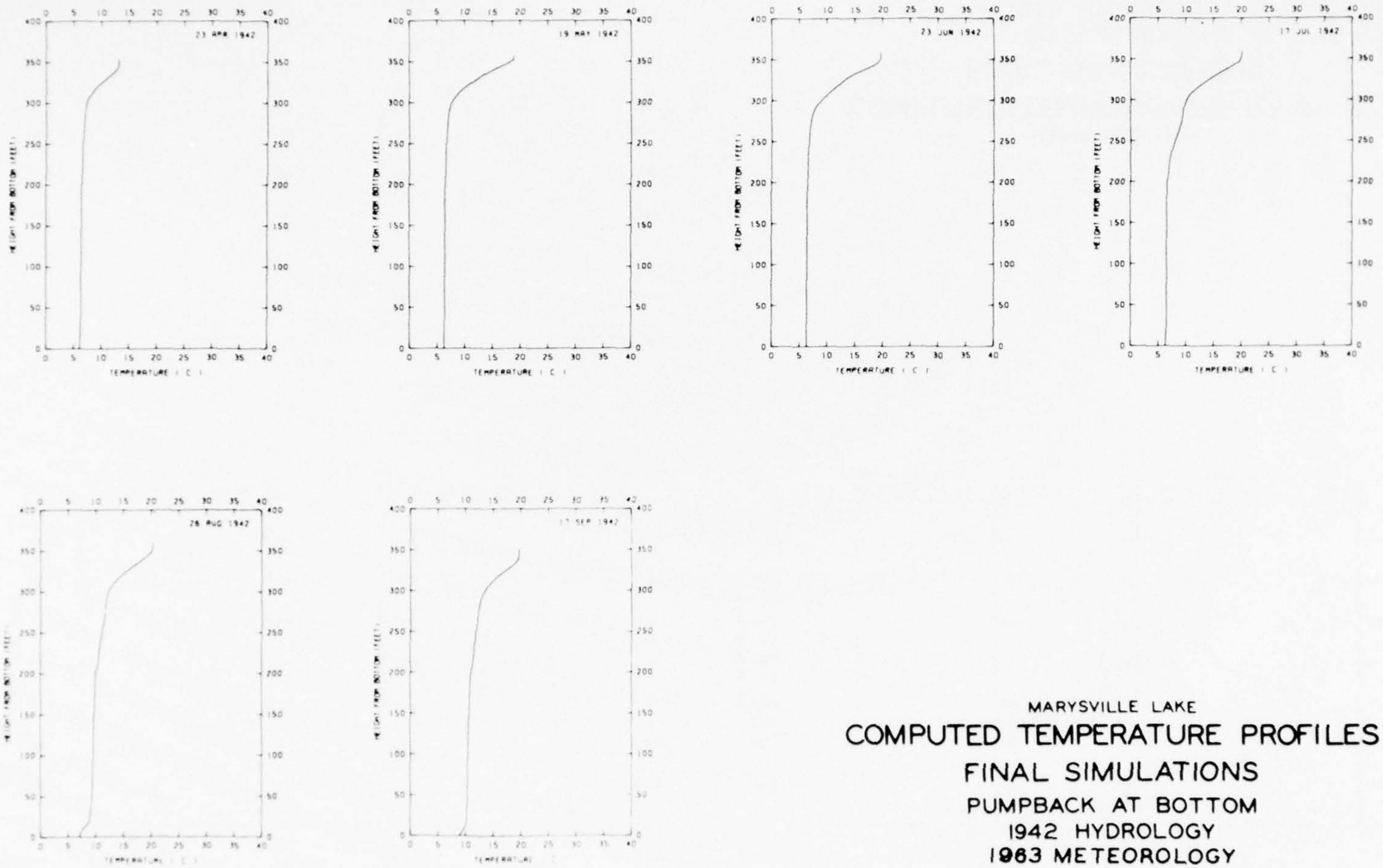
1962 HYDROLOGY

1962 METEOROLOGY

PLATE 2



MARYSVILLE LAKE
COMPUTED TEMPERATURE PROFILES
FINAL SIMULATIONS
NO PUMPBACK
1934 HYDROLOGY
1967 METEOROLOGY



MARYSVILLE LAKE

COMPUTED TEMPERATURE PROFILES

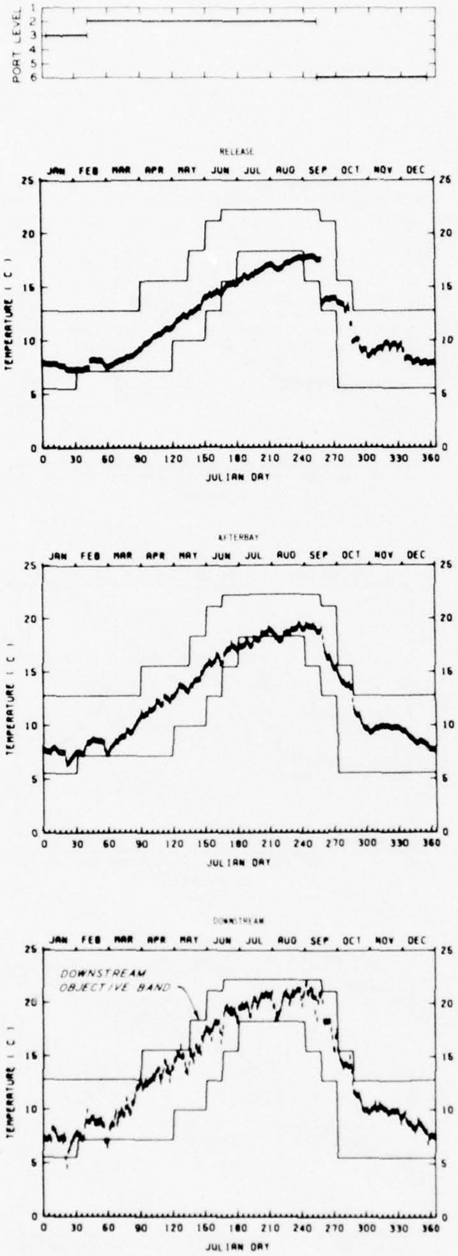
FINAL SIMULATIONS

PUMPBACK AT BOTTOM

1942 HYDROLOGY

1963 METEOROLOGY

PLATE 4

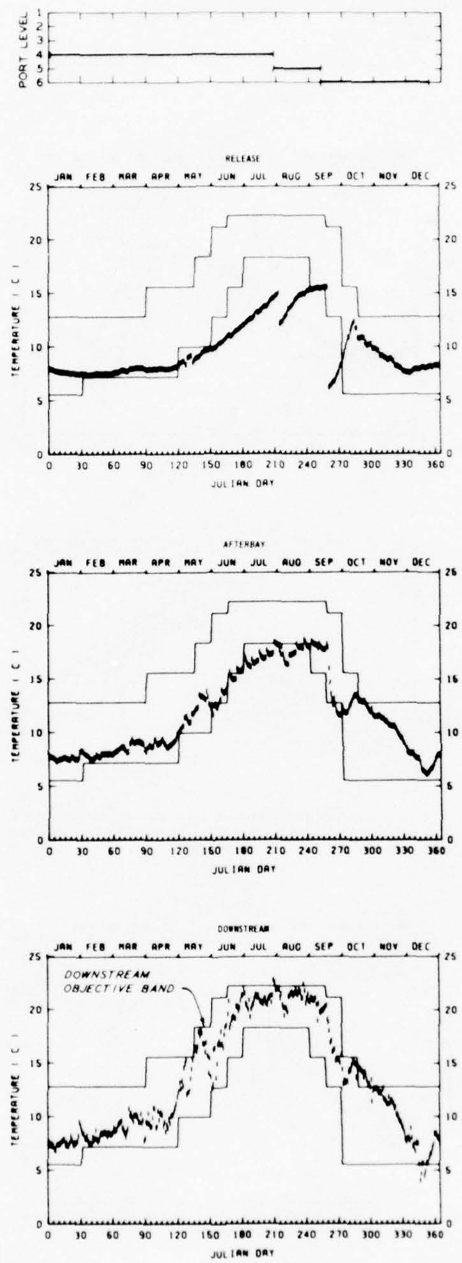


MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

FINAL SIMULATIONS

PUMPBACK AT BOTTOM
1962 HYDROLOGY
1962 METEOROLOGY



MARYSVILLE LAKE

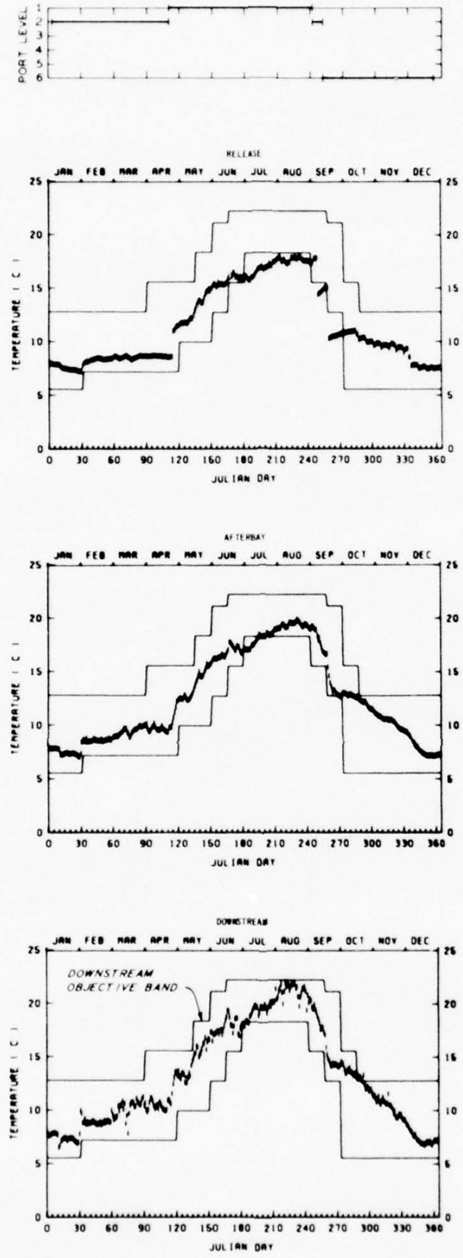
COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

FINAL SIMULATIONS

NO PUMPBACK

1934 HYDROLOGY

1967 METEOROLOGY

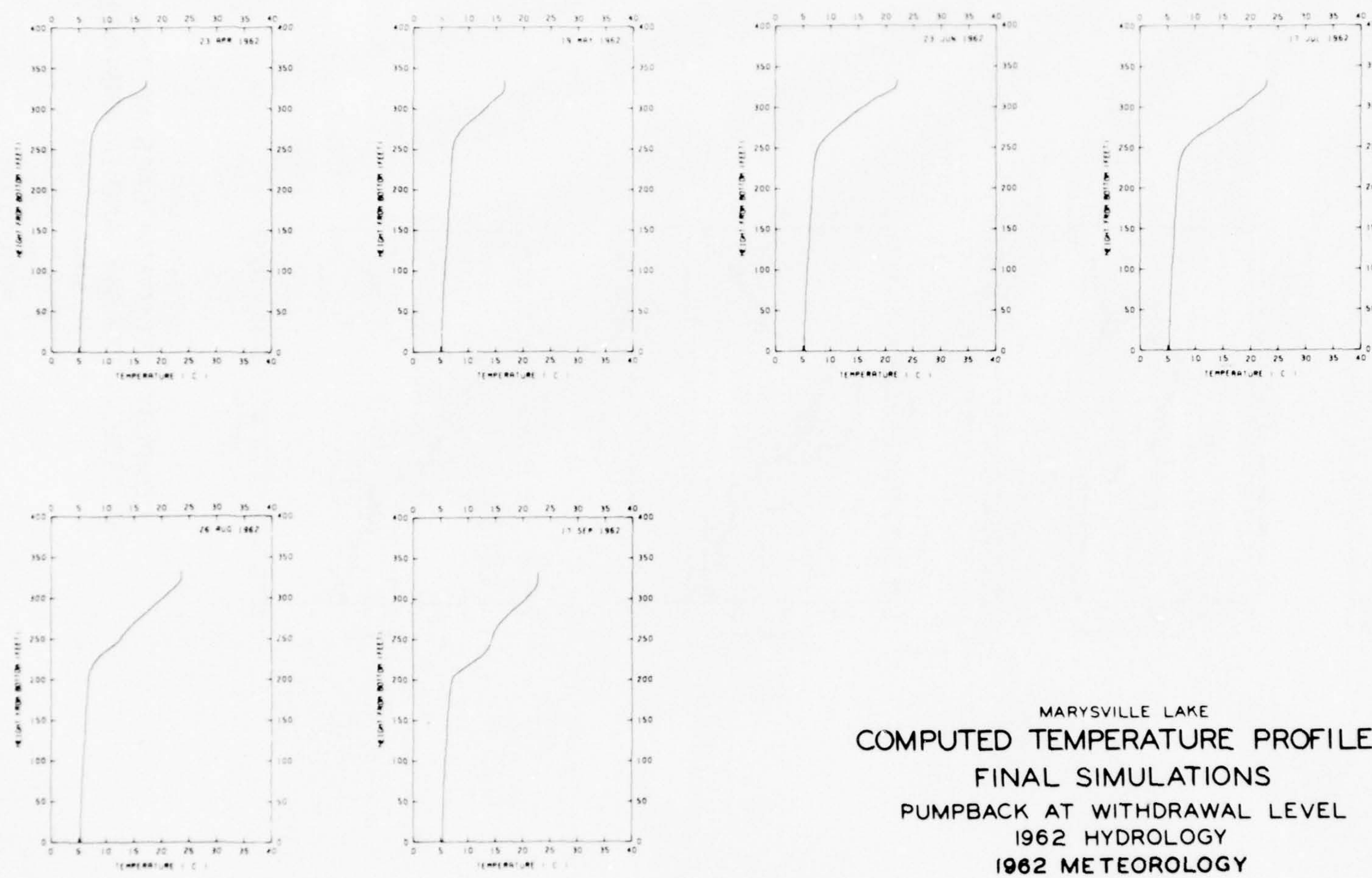


MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE
RELEASE, AFTERBAY, AND DOWNSTREAM

FINAL SIMULATIONS

PUMPBACK AT BOTTOM
1942 HYDROLOGY
1963 METEOROLOGY



MARYSVILLE LAKE

COMPUTED TEMPERATURE PROFILES

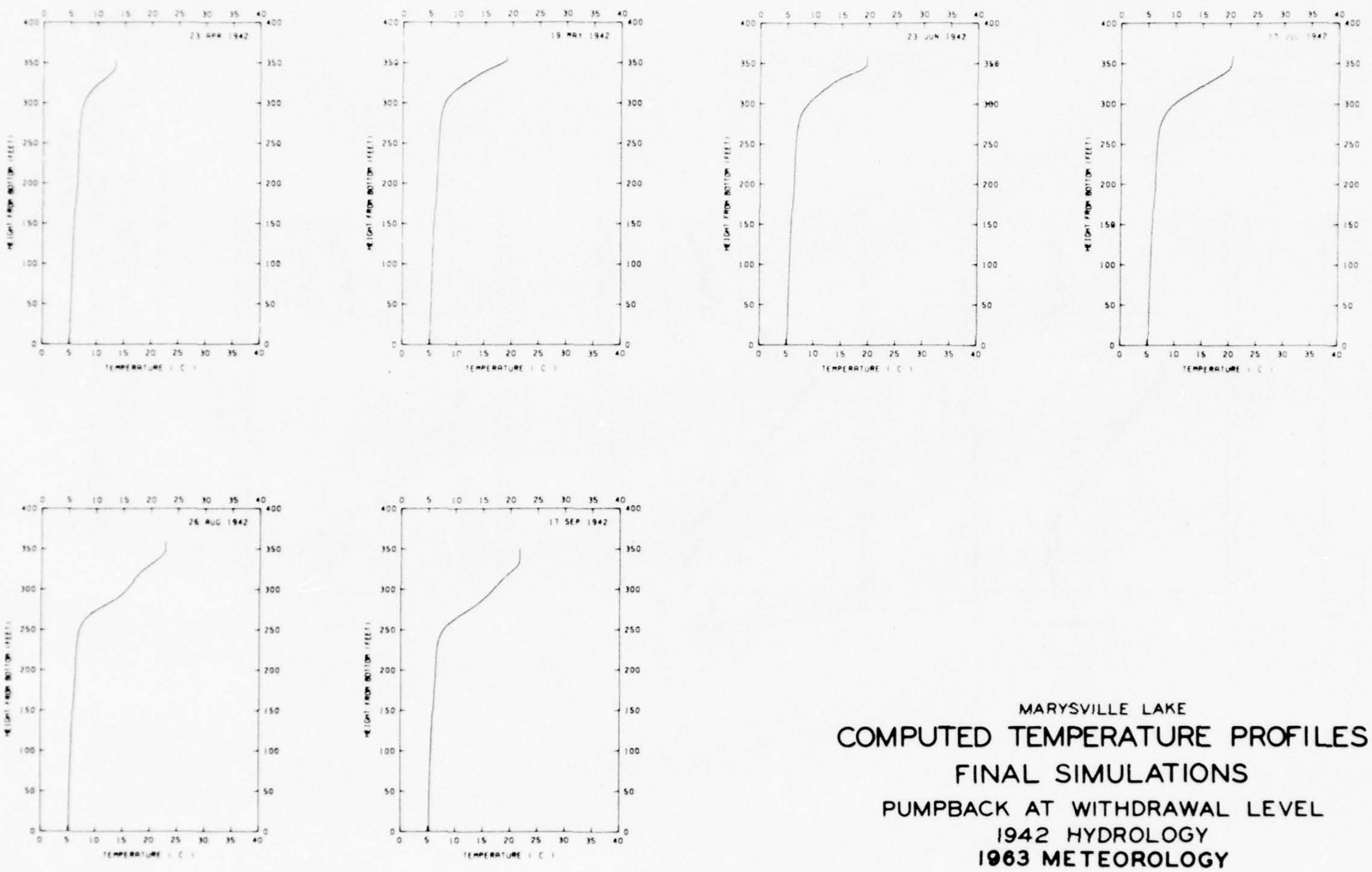
FINAL SIMULATIONS

PUMPBACK AT WITHDRAWAL LEVEL

1962 HYDROLOGY

1962 METEOROLOGY

PLATE 8



MARYSVILLE LAKE

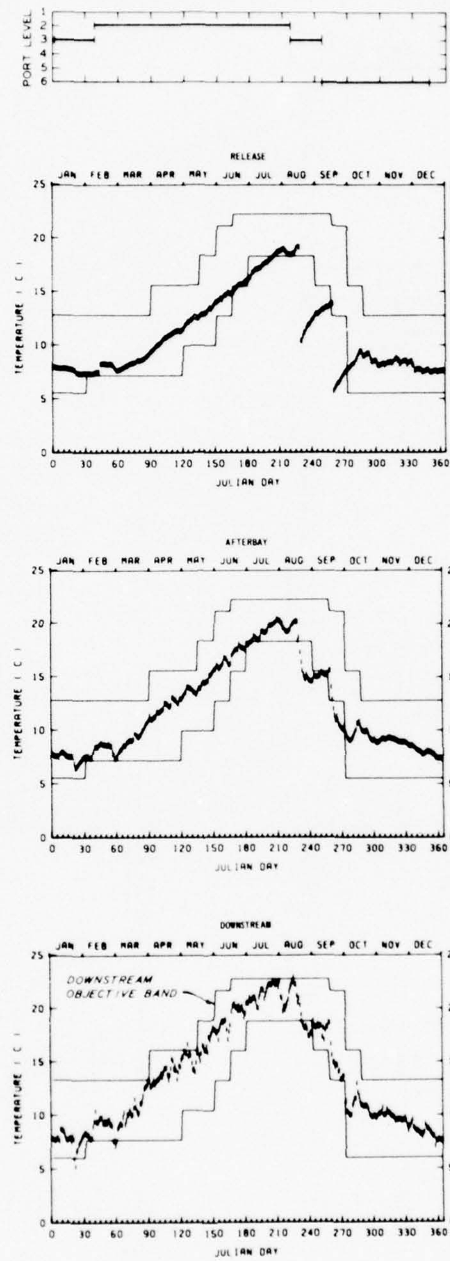
COMPUTED TEMPERATURE PROFILES

FINAL SIMULATIONS

PUMPBACK AT WITHDRAWAL LEVEL

1942 HYDROLOGY

1963 METEOROLOGY



MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

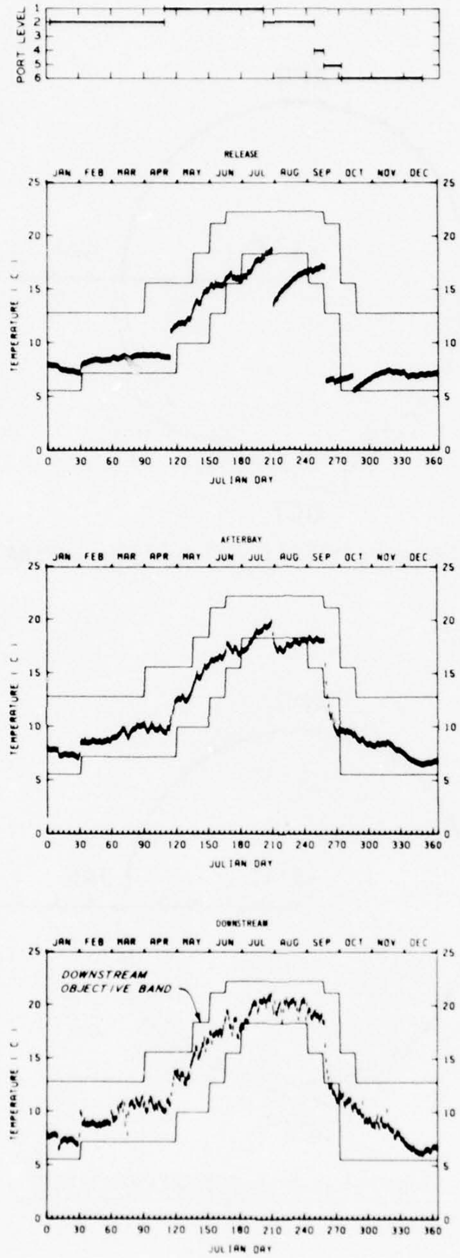
FINAL SIMULATIONS

PUMPBACK AT WITHDRAWAL LEVEL

1962 HYDROLOGY

1962 METEOROLOGY

PLATE 10

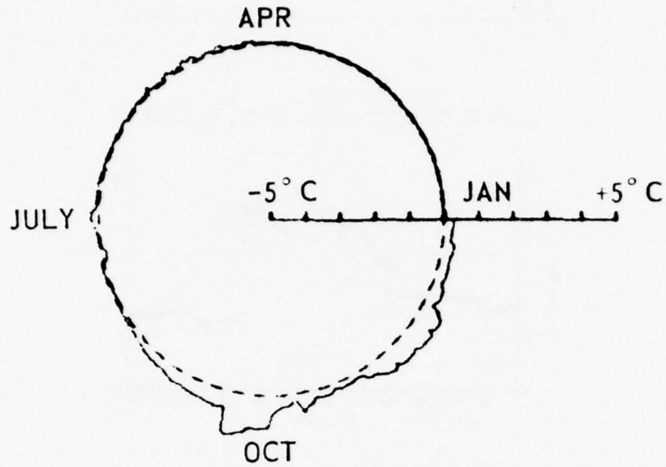


MARYSVILLE LAKE

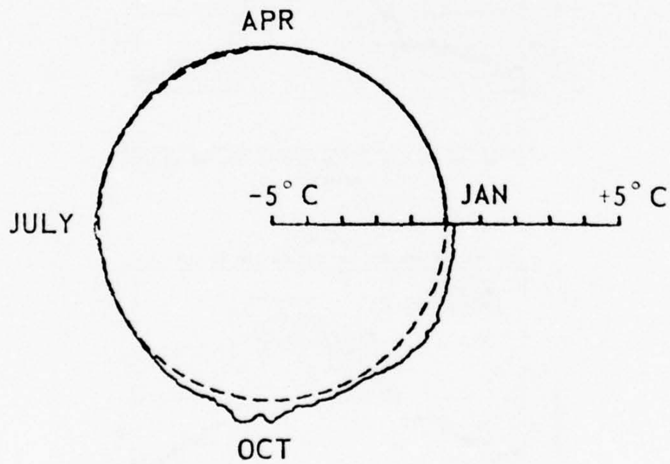
COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

FINAL SIMULATIONS

PUMPBACK AT WITHDRAWAL LEVEL
1942 HYDROLOGY
1963 METEOROLOGY



VARIATION IN MARYSVILLE LAKE RELEASE TEMPERATURE



VARIATION IN DOWNSTREAM TEMPERATURE

LEGEND

- - - - - - PUMPBACK AT BOTTOM, E = 2.5
———— PUMPBACK AT BOTTOM, E = 5.0

MARYSVILLE LAKE

EFFECT OF PUMPBACK ENTRAINMENT ON RELEASE AND DOWNSTREAM TEMPERATURES

STUDY YEAR 1

APPENDIX A: MARYSVILLE LAKE TEMPERATURE STUDY INITIAL MATHEMATICAL MODEL INVESTIGATIONS

PART I: INTRODUCTION

1. The Marysville Lake Temperature Study is currently being conducted at the U. S. Army Engineer Waterways Experiment Station (WES) for the U. S. Army Engineer District Sacramento (SPK). Both a physical model and a numerical simulation model will be used during the study. The study will consist of an initial mathematical model investigation, prior to the construction of the physical model, and then a detailed investigation using both physical and mathematical models. This procedure was used (a) to provide an early insight into the ability of Marysville Lake to meet downstream temperature objectives, (b) to permit comparison of results of the numerical simulations with and without the hydrodynamics as defined by the physical model, thereby providing some assessment of the benefit of a physical model investigation, and (c) to allow determination of proper values of coefficients to be used in subsequent simulations in order to provide the most reliable results possible from the simulations. The purpose of this preliminary report is to present the results of the initial mathematical model investigations.

2. The proposed Marysville Lake, with the dam at the Parks Bar Site on the Yuba River, will be about 360 ft deep with a volume of 916,000 acre-ft and an area of 6,640 acres at gross pool el 560. A selective-withdrawal facility will provide flows to the powerhouse. The project provides for pumped-storage power operations, using an afterbay immediately downstream of the dam.

3. The afterbay of Marysville Lake will be about 73 ft deep with a volume of 44,000 acre-ft and an area of 940 acres at gross pool el 233. A gated overflow spillway with sluices will control flow from the afterbay.

4. The Yuba River joins the Feather River approximately 14 miles below the Marysville Dam. It is at this confluence that temperature objectives are established.

PART II: MODEL DESCRIPTION

5. The downstream release characteristics and the internal structure of temperature for Marysville Lake were predicted using a numerical simulation model. The model (WESTEX) used in conjunction with this investigation was developed at WES based upon the results of Clay and Fruh,[1*] Edinger and Geyer,[2] Dake and Harleman,[4] and Bohan and Grace.[5]

6. The WESTEX model provides a procedure for examining the balance of thermal energy imposed on an impoundment. These energy balance and lake hydrodynamic phenomena are used to map vertical profiles of temperature in the time domain. The model includes computational methods for simulating heat transfer at the air-water interface, heat advection due to inflow and outflow, and the internal dispersion of thermal energy. The model is conceptually based on the division of the impoundment into discrete horizontal layers. Fundamental assumptions include the following:

- a. Isotherms are parallel to the water surface both laterally and longitudinally.
- b. The water in each discrete layer is isotropic and physically homogeneous.
- c. Internal advection (between layers within the lake) and heat transfer occur only in the vertical direction.
- d. External advection (inflow to and outflow from the lake) occurs as a uniform horizontal distribution within each layer.
- e. Internal dispersion of thermal energy is accomplished by a diffusion mechanism that combines the effects of molecular diffusion, turbulent diffusion, and thermal convection.

7. The surface heat exchange, internal mixing, inflow, and outflow processes are simulated separately, and their effects are introduced sequentially at daily intervals.

8. The WESTEX model employs an approach to the evaluation of surface heat transfer developed by Edinger and Geyer.[2] This method formulates equilibrium temperatures and coefficients of surface heat

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* See References, page A13.

exchange. Equilibrium temperature is defined as that temperature at which the net rate of heat exchange between the water surface and the atmosphere is zero. The coefficient of surface heat exchange is the rate at which the heat transfer process occurs. The equation describing this relationship is:

$$H = K(E - \theta) \quad (1)$$

where

H = net rate of surface heat transfer, Btu/ft^2/day

K = coefficient of surface heat exchange, Btu/ft^2/day/$^\circ$F

E = equilibrium temperature, $^\circ$F

θ = surface temperature, $^\circ$F

The computation of equilibrium temperature and heat exchange coefficient is based solely on meteorological data as outlined by Edinger, Duttweiler, and Geyer.[3]

9. The net heat exchange at the surface is composed of seven heat exchange processes:

a. Shortwave solar radiation.

b. Reflected shortwave radiation.

c. Long-wave atmospheric radiation.

d. Reflected long-wave radiation.

e. Heat transfer due to conduction.

f. Back radiation from the water surface.

g. Heat loss due to evaporation.

For every day of meteorological data, the seven heat exchange terms can be evaluated and the net heat exchange rate expressed in terms of an equilibrium temperature and an exchange coefficient.

10. All of the surface heat exchange processes, with the exception of shortwave radiation, affect only the top few feet of the lake. Shortwave radiation penetrates the water surface and increases the temperature at greater depths. Based on laboratory investigations, Dake and Harleman[4] have suggested an exponential decay with depth for describing the heat flux due to shortwave penetration.

11. The surface heat exchange concepts are implemented in the WESTEX model by the exponential penetration of a percentage of the incoming shortwave radiation and the placement of the effect of all other sources of surface heat exchange into the surface layer. This can be expressed mathematically by the following two equations:

$$H_S = K(E - \theta) - (1 - \beta)S \tag{2}$$

$$H_i = (1 - \beta)\ Se^{-\lambda z_i} \tag{3}$$

where

H_S = heat transfer rate into or out of surface layer, Btu/ft^2/day

β = shortwave radiation absorbed in the surface layer, percent

S = rate of total incoming shortwave radiation, Btu/ft^2/day

H_i = rate of heat absorption in layer (i), Btu/ft^2/day

e = natural logarithmic base (2.7183)

λ = absorption coefficient, ft^{-1}

z_i = depth below surface, ft

12. The process of inflow into a lake is simulated in WESTEX by the placement of inflow quantity and quality at that layer in which the density of the lake corresponds most nearly to the density of the inflow. Research efforts and physical model studies at WES indicate the existence of entrainment-induced density currents which flow upstream along the surface into the turbulent mixing zone caused by the inflow. Entrainment is implemented in the model by augmenting the inflow quantity with a volume from the surface layer (as discussed in paragraph 13). Characteristics of inflow and the entrained flow are averaged, and mixed values of density, temperature, and other water-quality parameters are determined. The mixed density is used to determine placement of the total quantity and mixed quality. In the model the process of inflow displaces upward a volume equal to the total inflow plus entrainment

quantity. This upward displacement is reflected in the model by an increase in the water surface. A corresponding decrease in water surface occurs as a result of the outflow process.

13. The volume of the entrained current is generally expressed as a percentage of the inflow quantity. Prior flume studies indicated that this percentage ranges from 25 to nearly 200. The percentage is thought to be a function of slope, width, flow quantity, density of inflow, and density within the lake, but analytical relationships have not yet been determined. Thus, a physical model is of significant benefit in the evaluation of entrainment. For these initial simulations, it was assumed that there is no entrainment current generated by the inflow.

14. The internal mixing process is simulated by a transfer of heat and other water-quality constituents between adjacent layers. The magnitude of the heat transfer between two layers is a percentage of the total heat transfer required to completely mix the two layers. The percentage is a mixing coefficient that is defined for every layer. Data input includes values of the mixing coefficient at the top and at the bottom of the lake. An exponential fit between the two extreme values is used to determine the appropriate coefficient at each layer. Because of the lack of knowledge concerning diffusion processes and the lack of justification for a more complex procedure, this simple diffusion analogy is applied to mixing between layers for temperature and other water-quality parameters.

15. The outflow component of the model incorporates the selective-withdrawal techniques developed at WES.[5] Transcendental equations defining the zero velocity limits of the withdrawal zone are solved with a half-interval search method. With knowledge of the withdrawal limits, the velocity profile due to outflow can be determined. The flow from each layer is then the product of the velocity in the layer, the width of the layer, and the thickness of the layer. A flow-weighted average is applied to water-quality profiles to determine the value of the release content of each parameter for each time step.

16. The lake regulation algorithms have been developed to realistically simulate the field operation of a selective-withdrawal system.

The selective-withdrawal system is assumed to be configured with an arbitrary number of selective-withdrawal intakes located in each of two wet wells with a separate floodgate. Maximum and minimum flows from each intake and from the floodgate must be specified. Also, the maximum flow for the selective-withdrawal system is specified. The algorithms attempt to numerically withdraw water at or near the objective temperature. Withdrawal will be from either one intake level, two adjacent intake levels, and/or the flood-control intake, depending upon the objective temperature, the temperature profile, the intake capabilities, and the amount of flow to be released.

17. Pumpback currents are represented in the model with the three processes of entrainment, mixing, and placement. Entrainment is expressed as a percentage of pumpback volume. The entrained water at its temperature is numerically mixed with the pumpback volume at its temperature. This total volume of water at the mixed temperature is placed into the lake at the appropriate density level. The vertical location from which entrainment takes place and the percentage of entrainment are required as data input to the model. A physical model is of great benefit for assessment of these parameters.

PART III: DEVELOPMENT OF INPUT DATA

18. At the request of SPK an average hydrologic year (1962) was used for the initial simulations. For calibration purposes simulations were conducted with meteorological data from 1974 and 1975 and hydrological data from 1962.

19. Meteorological data from Beale Air Force Base were used for this study. The required data consisted of dry bulb temperature, dew point temperature, wind speed, and cloud cover. For 1962, these data were obtained from the National Climatic Center, Asheville, North Carolina. For 1974 and 1975, these data were obtained from SPK.

20. Based on a projected operation study, mean monthly inflows and outflows were provided by SPK. Since daily input is required by the WESTEX model, the mean monthly value was used for each day of the appropriate month.

21. Although New Bullard's Bar Reservoir is immediately upstream of Marysville Lake and will contribute the majority of inflow to the project, New Bullard's Bar Reservoir was not numerically simulated. This decision was based on the lack of adequate input data for a numerical simulation as well as uncertainties about the selective withdrawal characteristics of the New Bullard's Bar Intake structure. Observed stream temperature data were available below Colgate powerhouse, the location at which the New Bullard's Bar releases are discharged to the Yuba River. By combining these data with observed stream temperature data on the upstream South Yuba River, a range of input stream temperature data was established. Three sets of input stream temperatures were tested for the initial simulations. The results of the simulations were relatively insensitive to the variations of input temperatures used; therefore, one set of input stream temperatures was used for all subsequent simulations. Plate A1 shows the inflow temperatures that were used. These temperatures were computed as a flow-weighted average of New Bullard's Bar Reservoir release flows and South Yuba River flows.

22. Temperature objectives at the confluence of the Yuba and Feather Rivers were furnished to WES by SPK. The objectives consisted

of an upper and lower limit on stream temperature as functions of time through a one-year period. These limits are shown on the plots of predicted temperature at the confluence (identified as "downstream" on the various plates).

PART IV: MODEL CALIBRATION

23. As has been discussed previously, the WESTEX model requires the determination of coefficients of surface heat exchange distribution and internal mixing. For Marysville Lake, these coefficients were determined by conducting simulations with 1974 and 1975 meteorologic data. Coefficients were adjusted and the simulation was repeated until the predicted temperature profiles corresponded in shape and range to those observed during 1975 in the nearby New Bullard's Bar and Englebright Reservoirs. The operation of the outlet works used in these simulations was representative of the New Bullard's Bar Reservoir. The following coefficients were determined from this analysis:

$$\beta = 0.95$$

$$\lambda = 0.3$$

$$\alpha_1 = 0.1$$

$$\alpha_2 = 0.1$$

where

β = percentage of incoming shortwave radiation absorbed in the surface layer

λ = absorption coefficient

α_1 = mixing coefficient at surface

α_2 = mixing coefficient at bottom

24. It should be noted that the value selected for β (0.95) is large relative to values used by WES engineers in previous thermal studies. A large value of β might traditionally be used to represent an extremely turbid impoundment, that is, one in which light penetrations were severely restricted. In the past, β has been selected for a 2-ft-layer thickness and, although it is assumed that Marysville Lake will be relatively clear, this value of β was needed to account for the use of 10-ft vertical layers in the mathematical simulations.

PART V: MODIFICATIONS

25. Several modifications were made to the WESTEX model to account for the effects of pumped storage operations at Marysville Lake and to compute the stream temperature at the confluence of the Yuba and Feather Rivers.

26. The WESTEX model is incapable of simulating exactly the unique configuration of the intake structure proposed for Marysville Lake. The model requires that flows be released through one or two wet-wells containing selective-withdrawal intakes and a single floodgate. The proposed structure consists of six wet wells, each with a floodgate and 10-ft temperature shutters from just above the floodgate to the top of the tower. For the initial simulations, one floodgate level and three levels of selective-withdrawal intakes were assumed. The center-line elevation of the floodgate level was 250 ft and the center-line elevations of the selective-withdrawal intakes were 375, 440, and 500 ft. Blending of flow was allowed by combining the six wet wells into two. This provided for blending between adjacent port levels and/or the floodgate which greatly reduced the numerous possibilities by which blending could be achieved with six wet wells. All pumpback flows were assumed to pass through the floodgate.

27. To enable the WESTEX model to account for pumped storage operations, it was necessary to account for the effect of the afterbay on the temperature of the generated release. It was assumed that the afterbay will remain fully mixed. The heat exchange at the air-water interface in the afterbay was taken into account in a manner similar to that for Marysville Lake. The combined effect of this heat exchange at the air-water interface and the temperature of the generation flows yielded the mixed temperature of the afterbay. This temperature was used as the temperature of the pumpback flow and of the afterbay release.

28. An observation of the Richard B. Russell Lake Water Quality Study[6] was that a pumpback jet entering the reservoir entrained an amount of reservoir water resulting in an upstream current greater in magnitude than the amount of flow being pumped. For Marysville without

the benefit of the physical model, this entrained flow was assumed to come from the area of the reservoir immediately above the floodgate opening. Two values of entrainment were assumed, 0 and 100 percent.

29. A daily power operation schedule has not been established for Marysville Lake. For this study, SPK provided WES with maximum and minimum generation flow rates. Assuming a 4-hr generation period, the generation flow rates analyzed were 1,500, 24,000, and 50,000 cfs. As a base condition, one simulation was made assuming no generation or pumpback flow.

30. Since the objective temperatures for this project are at the confluence of the Yuba and Feather Rivers, the afterbay release temperatures must be routed approximately 10 miles downstream. This routing is accomplished by assuming a fully mixed flow and using the relationship of Edinger and Geyer.[2]

$$T_x = (T_0 - E)\, e^{\alpha} + E$$

$$\alpha = -Kx/\gamma C_p y U$$

where

T_x = downstream water temperature, °F

T_0 = initial water temperature, °F

E = equilibrium temperature, °F

K = coefficient of surface heat exchange, Btu/ft^2/day/°F

x = downstream distance, ft

γ = specific weight of water, 62.4 lb/ft^3

C_p = specific heat of water, 1.0 Btu/lb-°F

y = mean stream depth, ft

U = mean stream velocity, ft/day

The values of equilibrium temperature and coefficient of surface heat exchange were those used for Marysville Lake for the appropriate day.

Additionally, for the initial simulations, no attempt was made to incrementally route flow down the Yuba, but instead a constant value of mean stream depth (6 ft) and mean stream velocity (6 fps) were used to accomplish the routing in one step.

PART VI: DISCUSSION

31. The results of the simulations in the form of time-histories of computed temperature of the release, in the afterbay, and downstream for 1962 and computed thermal profiles in Marysville Lake for various dates during the period April-September 1962 are presented in Plates A2-A7. Plates A2 and A3 present the base condition results with no power flow. Plates A4 and A5 present the results for generation and pumpback flows with the assumption of 100 percent entrainment of flow by the pumpback jet. Plates A6 and A7 present the results for generation and pumpback flows assuming no entrainment of flow by the pumpback jet.

32. The results indicate the ability of the project to meet temperature objectives. Inspection of the computed Marysville Lake thermal profiles shows the lake to be less thermally stratified for the generation and pumpback flows with 100 percent pumpback entrainment than flow with no entrainment. It is believed that the ability of the project to meet temperature objectives is primarily related to the hydrodynamics of the lake. Caution should therefore be exercised in drawing any conclusions from these results, since simplifying assumptions about the hydrodynamics were made for this analysis. The results of the physical and advanced mathematical modeling efforts on the Marysville Lake Project will determine the validity of these assumptions. Only after the hydrodynamics of Marysville Lake have been properly defined can any modifications to the project be analyzed.

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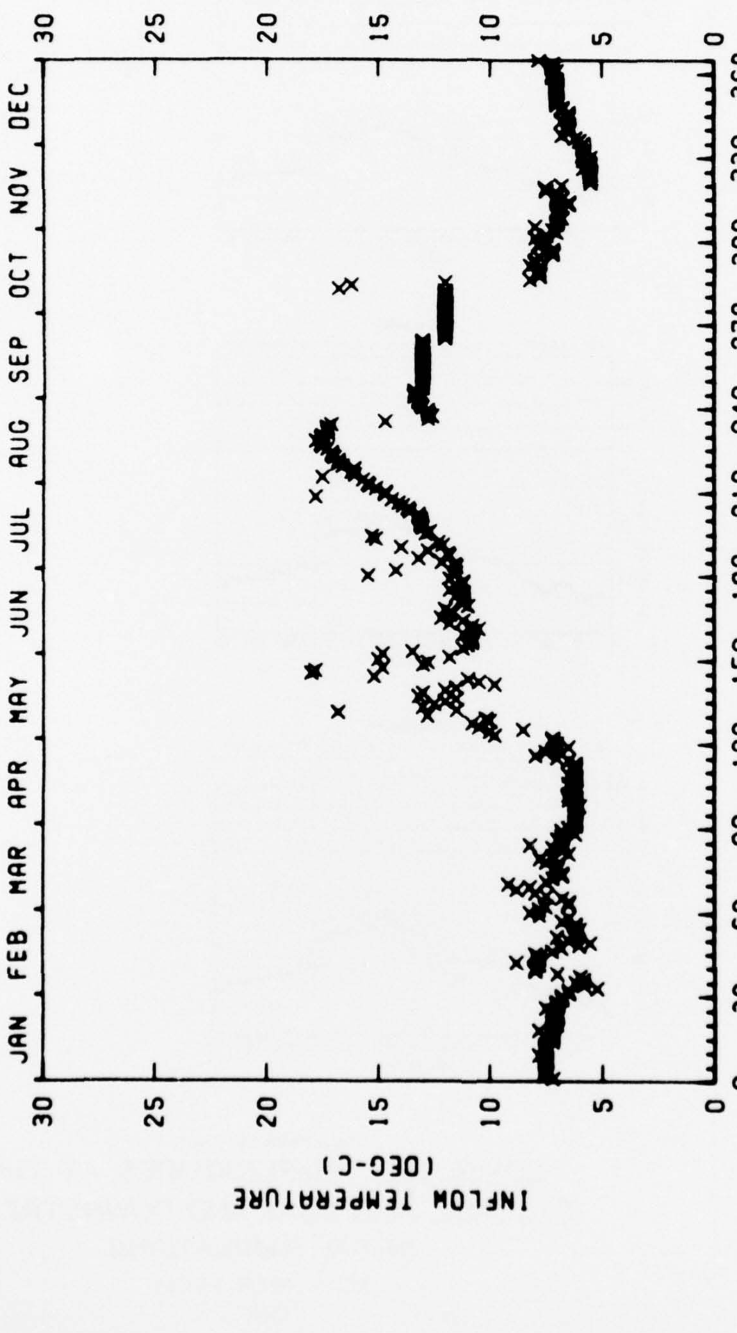
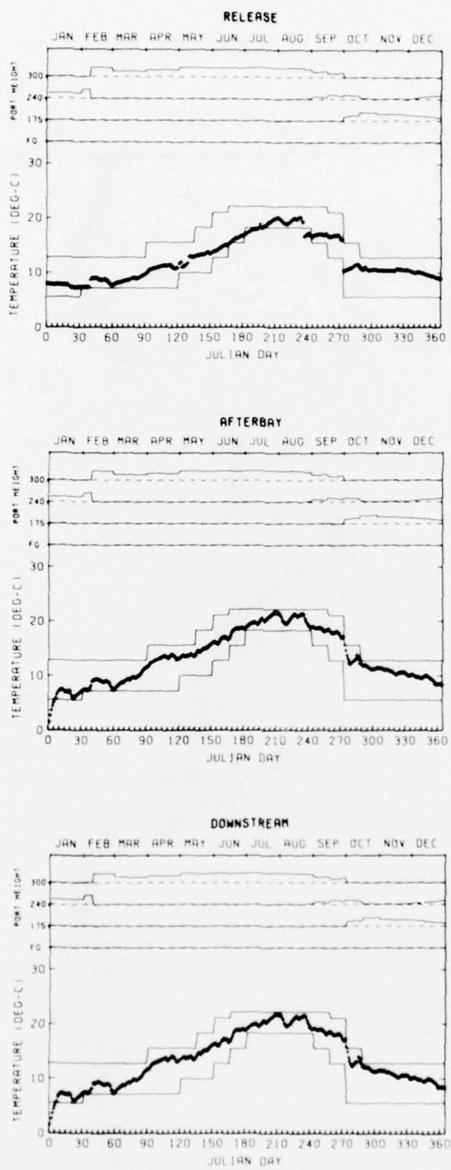


MARYSVILLE LAKE
COMPUTED INFLOW TEMPERATURES



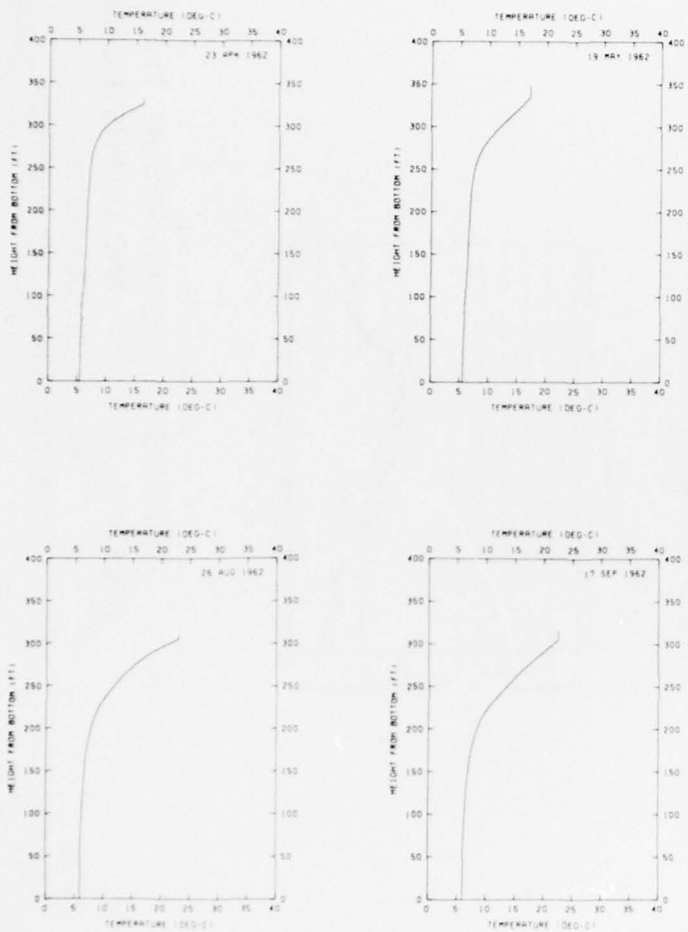
MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

INITIAL SIMULATIONS

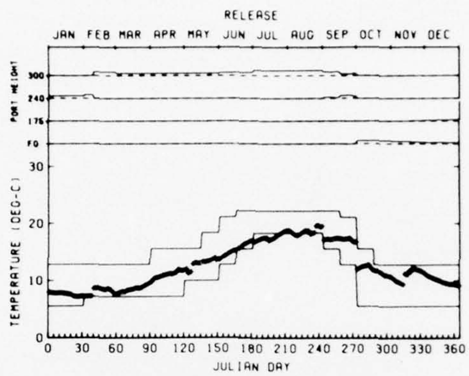
NO POWER FLOW

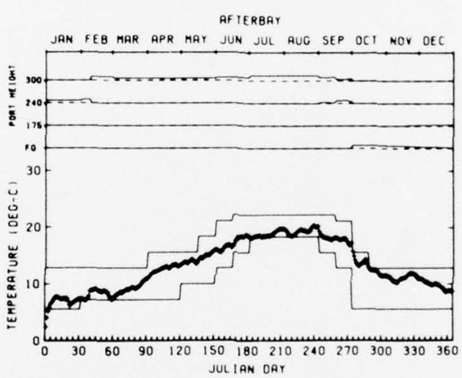
1962

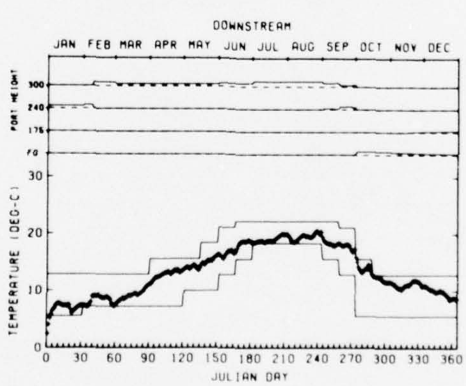


MARYSVILLE LAKE
COMPUTED TEMPERATURE PROFILES
INITIAL SIMULATIONS
NO POWER FLOW
1962

PLATE A3







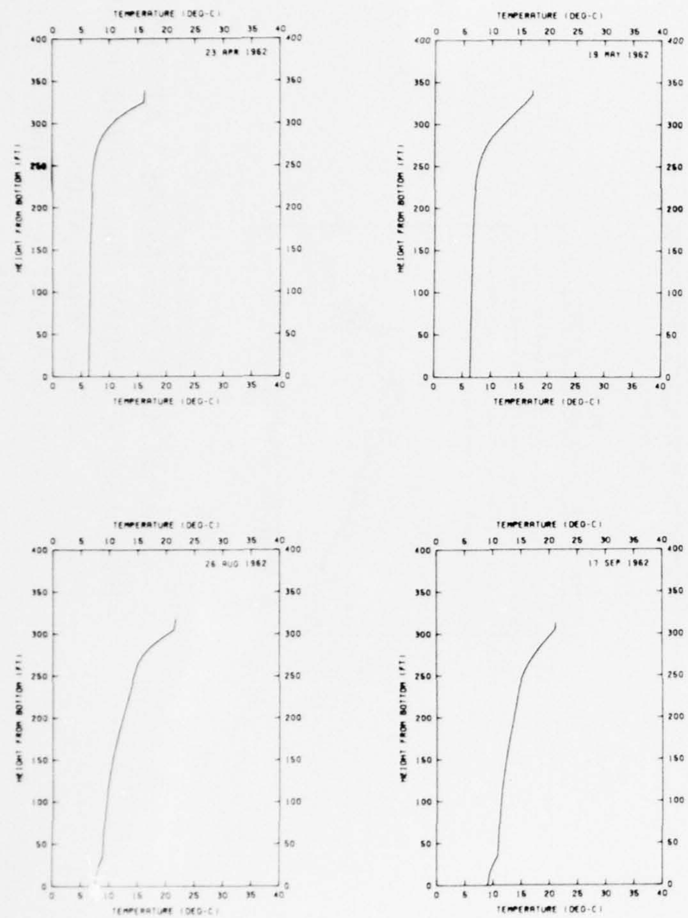
MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

INITIAL SIMULATIONS

100% ENTRAINMENT BY PUMPBACK

1962



MARYSVILLE LAKE

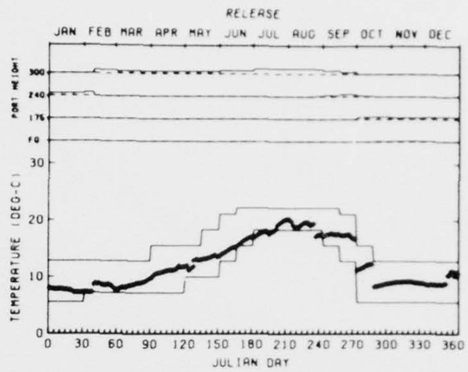
COMPUTED TEMPERATURE PROFILES

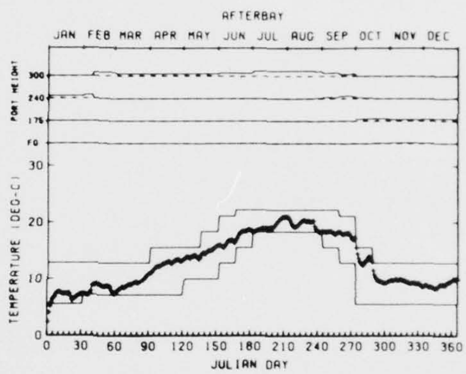
INITIAL SIMULATIONS

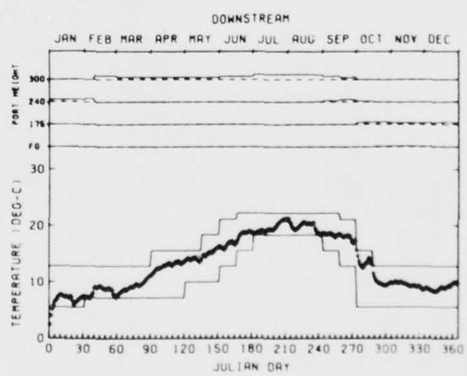
100% ENTRAINMENT BY PUMPBACK

1962

PLATE A5







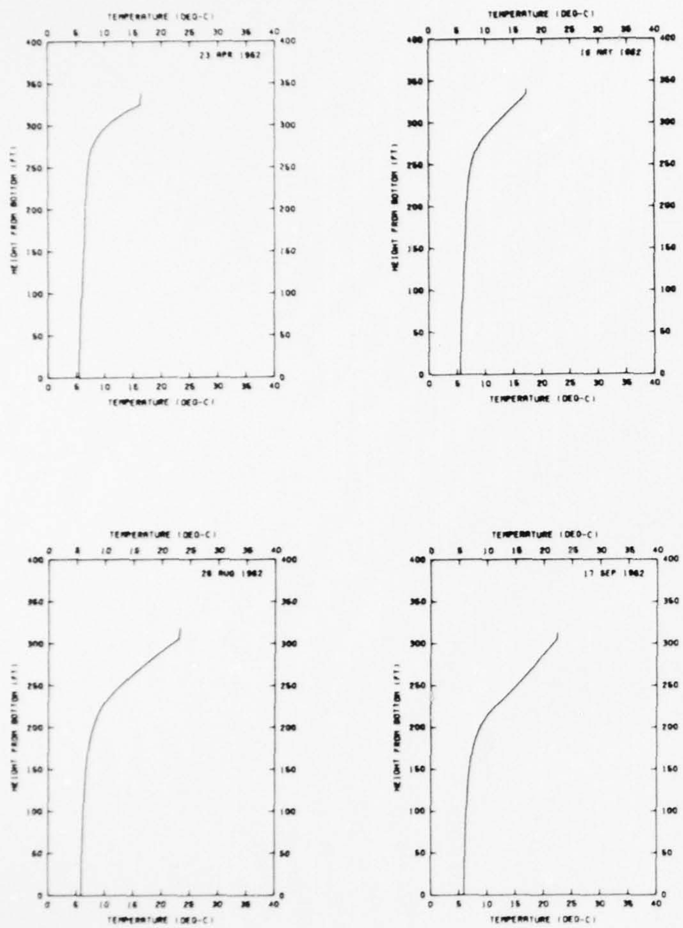
MARYSVILLE LAKE

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

INITIAL SIMULATIONS

NO ENTRAINMENT BY PUMPBACK

1962



MARYSVILLE LAKE

COMPUTED TEMPERATURE PROFILES

INITIAL SIMULATIONS

NO ENTRAINMENT BY PUMPBACK

1962

APPENDIX B: SELECTIVE WITHDRAWAL ANALYSIS

1. The WES generalized selective withdrawal technique[3*] uses the following equation to compute the upper and lower limits of withdrawal for an orifice:

$$Z = \left(\frac{V_o A_o}{\sqrt{\frac{\Delta\rho}{\rho_o} g}} \right)^{0.40} \qquad \text{(B1)}$$

where

Z = vertical distance from the elevation of the orifice center line (℄) to the upper or lower limit of the zone of withdrawal, ft

V_o = average velocity through the orifice, fps

A_o = area of the orifice opening, sq ft

$\Delta\rho$ = density difference of fluid between the elevations of the orifice ℄ and the upper or lower limit of the zone of withdrawal, g/cc

ρ_o = fluid density at the elevation of the orifice ℄, g/cc

g = acceleration due to gravity, ft/sec^2

The product of V_o and A_o gives the outflow rate (in cfs) through the orifice. Therefore, knowing the port discharge, Z can be determined from Equation B1.

2. The selective withdrawal studies[3] were conducted for single and multiple vertical orifices, so there is no problem in applying the technique to a single horizontal port. However, when applying the technique to simultaneous discharge through multiple horizontal ports (all at the same level), the question has been raised whether to use in computing the withdrawal limits the discharge and port area for a single port or the sum of the discharges and cumulative port area for all the ports operating at that level. Because the preliminary design for the

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* See References, page 45.

Marysville project includes six ports at each level, this question had to be answered.

3. The logical application of Equation B1 was to use the discharge and port area for a single port since the equation was developed for a single port. Assuming that equal simultaneous releases would occur through each port, the withdrawal characteristics and release temperatures for a single port would apply to all the ports at that level. The validity of this approach was tested before incorporation into the Marysville simulation model.

4. A series of tests were conducted in an existing 3-ft-wide by 2-ft-deep by 25-ft-long flume constructed of transparent plastic to evaluate the withdrawal characteristics of multiple ports releasing simultaneously from the same level of a density stratified pool. Because of the dimensional limitation of the flume width, it was only possible to model four of the six ports. This was considered to be sufficient for determining the effect of multiple horizontal ports. Each port was 0.1 ft wide by 0.02 ft high or had a width five times larger than the height. Flow from each port was regulated with a rotameter and gate valve and could be varied from 0.0004 to 0.0027 cfs. Density stratification was achieved with saline and fresh waters. Conductivity and temperature sensors, calibrated against known densities, were used to measure density. Velocity distributions were determined from video recordings of dye streak displacement.

5. The test results indicated that, with all four ports simultaneously discharging, the observed limits of withdrawal and release densities could more accurately be predicted by using the flow rate and port area for one of the ports rather than the total flow rate and port area. Therefore, the Marysville simulation model was coded so the discharge through a single port, which is obtained by dividing the total generation release rate by 6 (for 6 turbines), is used to compute the limits of withdrawal.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

Fontane, Darrell G
Marysville Lake hydrothermal study; Report 1: 900-MW project; hydraulic and mathematical model investigation, by Darrell G. Fontane, Mark S. Dortch, Charles H. Tate, Jr., [and] Bruce Loftis. Vicksburg, U. S. Army Engineer Waterways Experiment Station, 1977.
1 v. (various pagings) illus. 27 cm. (U. S. Waterways Experiment Station. Technical report H-77-5, Report 1)
Prepared for U. S. Army Engineer District, Sacramento, Sacramento, California.
Includes bibliography.

1. Hydraulic models. 2. Marysville Lake. 3. Mathematical models. 4. Pumped-storage. 5. Water temperature. I. Dortch, Mark S., joint author. II. Loftis, Bruce, joint author. III. Tate, Charles H., joint author. IV. U. S. Army Engineer District, Sacramento. (Series: U. S. Waterways Experiment Station, Vicksburg, Miss. Technical report H-77-5, Report 1)
TA7.W34 no.H-77-5 Report 1